PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

MUSEUM OF VICTORIA
1 MAR 1999

Edited by M. R. Banks and M. J. Brown

and Published by the Society

Hobart

Tasmania

31 DECEMBER 1998

VOLUME 132

PAPERS AND PROCEEDINGS OF

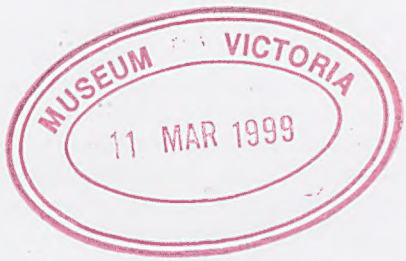
THE ROYAL SOCIETY OF TASMANIA

Edited by M. R. Banks and M. J. Brown

and Published by the Society

Hobart

Tasmania



Monotone Art Printers

ISSN 0080-4703

31 DECEMBER 1998

VOLUME 132

Museum Victoria
71410

COUNCIL AND OFFICE BEARERS

Patron
Her Majesty the Queen

President
His Excellency, the Honourable Sir Guy Green AC, KBE
The Governor of Tasmania

Vice-Presidents

Dr John Thorne
Dr Shirley Jeffrey AM

Council

Mr Alan Blow OAM, QC
Mrs Michelle de Quincey
Professor Campbell Macknight
Mr Ken Milton (resigned)
Dr Andrew Rozefelds
Dr Steven Smith (resigned)
Mr Chris Tassell
Dr Brian Yates
Mr Ron Banks (Past Vice-President)

Honorary Secretary
Dr Michael Readett

Honorary Treasurer
Dr David Leaman

Honorary Auditor
Mr W. Anning BEc, FCA

Honorary Editor
Dr Max Banks AM

Honorary Assistant Editor
Dr Mick Brown

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 132

Contents

page

Annual report iv

Refereed papers:

VILIZZI, L. & WALKER, K.F. — Age profile of carp (*Cyprinus carpio* L.) in Lake Crescent, Tasmania 1

BRIDLE, K.L. & KIRKPATRICK, J.B. — Why do tall herbs rarely dominate Tasmanian alpine vegetation? Evidence from islands in the Ouse River system 9

MARSDEN-SMEDLEY, J.B. — Changes in southwestern Tasmanian fire regimes since the early 1800s 15

KIRKPATRICK, J.B. & GIBSON, N. — Responses to waterlogging and frost related to the topographic sequences of eucalypt species at three sites in central Tasmania 31

KIERNAN, KEVIN — Holocene landscape instability in the Dazzler Range, northern Tasmania 35

DALTON, P.J. — New locality records for some rare mosses in Tasmania 41

GARDNER, C. — The first record of larvae of the giant crab *Pseudocarcinus gigas* in the plankton 47

CANARIS, A.G. & KINSELLA, J.M. — Helminth parasite communities in four species of shorebirds (Charadriidae) on King Island, Tasmania 49

BICKEL, DANIEL J. — *Cunomyia*, a distinctive new hilarine fly genus from the Tasmanian World Heritage Area (Diptera: Empididae) 59

SHERWOOD, J., WALLS, J.T & RITZ, D.A. — Amathamide alkaloids in the pycnogonid, *Stylopallene longicauda*, epizoic on the chemically defended bryozoan, *Amathia wilsoni* *65*

BUCHANAN, A.M. — The presumed extinct *Argentipallium spiceri* (Asteraceae) rediscovered in Tasmania 71

Publication of this volume was generously supported by the Government of Tasmania and the University of Tasmania.

ROYAL SOCIETY OF TASMANIA
Annual Report for the Year 1997

The Council has the honour to present to members the following report on the activities of the Society during the year.

Council and Office Bearers

Patron
Her Majesty the Queen

President
His Excellency, the Honourable Sir Guy Green AC, KBE
The Governor of Tasmania

Vice-Presidents
Dr John Thorne
Dr Shirley Jeffrey AM

Council
Mr Alan Blow OAM, QC
Mrs Michelle de Quincey
Professor Campbell Macknight
Mr Ken Milton (resigned)
Dr Andrew Rozefelds
Dr Steven Smith (resigned)
Mr Chris Tassell
Dr Brian Yates
Mr Ron Banks (Past Vice-President)

Honorary Secretary
Dr Michael Readett

Honorary Treasurer
Dr David Leaman

Honorary Auditor
Mr W. Anning BEc, FCA

Honorary Editor
Dr Max Banks AM

Honorary Assistant Editor
Dr Mick Brown

President

His Excellency, Sir Guy Green, took the Chair as President of the Society at the Annual General Meeting of the Society, and at that of the Northern Branch. He presented the R.M. Johnston Medal to Professor Peter Sculthorpe AO, OBE, on 28 November and, accompanied by Lady Green, attended the Society's Christmas Function, later the same day.

Sir Guy Green, as President, presented a Royal Society Bursary to Andrew Job of Rokeby on 8 May 1997. The Bursary was to help Andrew represent Australia at the Canada Wide Science Fair in Regina, Saskatchewan.

Bereavements

Mr Phil Andrews (a member since 1966) died 10 February. He was well known and well respected in his field as Curator of Vertebrate Zoology at the Tasmanian Museum and Art Gallery. Several of his papers have appeared in the *Papers and Proceedings* of the Royal Society.

Mr J.R. Erp (a member since 1950) died in March 1977.

Mr H.B. Fowler (a member since 1961) was a long-standing and active member of the Northern Branch.

Mrs R. Millington (a member since 1974) died in March 1997.

Dr Jim Rogers (a member since 1959), a past Vice-President of the Society, died on 15 September. He had wide interests in biology and was Secretary of the Biological Club at the time of his death. Dr Rogers had a distinguished career in the army and followed his wartime experience with much voluntary work to help in the eradication of trachoma. He was also involved in astronomy, sport and education.

Miss J.C. Williams (a member since 1953) died in August 1997. Miss Williams regularly attended meetings of the Northern Branch.

Honours and Awards to Members

Professor Patrick Quilty was appointed a Member of the Order of Australia in the 1997 Queen's Birthday Honours List. The appointment was for service to geoscience, particularly Australian Antarctic scientific research, and its international promotion.

Mr George Brown was appointed a Member of the Order of Australia in the 1997 Australia Day Honours List.

The appointment was for service to the community particularly through the Winston Churchill Fellows Association of Tasmania and the Tasmanian Branch of the National Trust.

Ms Patricia Sabine was named Telstra Business Woman of the Year for 1997. Ms Sabine is Director of the Tasmanian Museum and Art Gallery, and has served on the Council of the Royal Society.

Dr Winifred Curtis was named as Hobart City Council's Australia Day Citizen of the Year for 1996. Dr Curtis has given a lifetime of service to Botany in Tasmania, has written many books, and (at 91 years of age) still works regularly at the Herbarium at the University of Tasmania.

Professor Terry Dwyer was appointed a Member of the Order of Australia in the 1998 Australia Day Honours List. The appointment was for services to medical research.

Mr Andrew Koo was appointed a Member of the Order of Australia in the 1998 Australia Day Honours List. The appointment was for service to the community. particularly through vocational education and training.

Membership

The membership is 409, an increase of 6 relative to 1996 and is made up as follows:

President	1	
Honorary Members	6	(2)
Life Members	30	(9)
Ordinary Members		
receiving *Papers & Proceedings*	238	(37)
not receiving *Papers & Proceedings*	112	(33)
Associate Members	22	(7)
TOTAL	409	(88)

Figures in brackets represent Northern Branch members.

Staff

The Society would like to place on record their thanks to Ms Vicki Farmery and Ms Joanna Huxley for their help throughout the year.

Council Meetings

Four meetings of Council were held during the year. Many topics were discussed, particularly the Royal Society of Tasmania Foundation, the Royal Society Bursaries, new Royal Society Medals, and the assessment of the viability of a branch of the Society in northwestern Tasmania.

The Royal Society of Tasmania Foundation

The Royal Society Foundation has continued to seek funds for the future development of the Society and invest those funds so that in future years the Society will have the capacity to undertake projects, thus enabling it to more appropriately meet its objectives.

In the past year, the Foundation has sought to raise support from members and will aim to widen its appeal in 1998.

At December 1997, the Foundation had invested the sum of $51 769.00.

Currently the Foundation is seeking ways and means of obtaining tax deductibility for donations.

Honours and Honours Committee

The Honours Committee, Dr S.W. Jeffrey, Chair (marine science), Professor J.B. Reid (plant science), Mr D.G. Hannan (geomorphology) and Professor M. Roe (history), formulated two new awards during 1997 which were accepted by the Royal Society Council and membership.

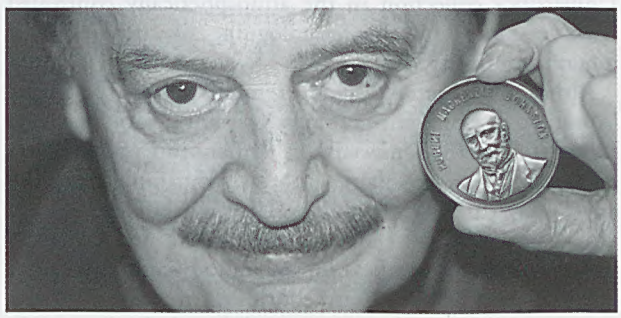
The first new award is a medal to recognise outstanding achievement by a scholar in mid-career. This medal, to be known as the M.R. Banks medal, honours Dr Max Banks for his contributions to science and the Royal Society in Tasmania.

The first recipient will be Dr Trevor McDougall, Chief Research Scientist (CSIRO Marine Research) and Fellow of the Australian Academy of Science, awarded for outstanding contributions to knowledge of ocean mixing processes. Such information is critical to more accurate modelling of climate change. The inaugural award will be presented to Dr McDougall at the March 1998 Royal Society Meeting.

The second new award will honour a young postdoctoral academic who has made significant advances in his/her field at an early stage of his/her career. The award will be made not more than five years after the PhD graduation and may be in any field within the purview of the Society. The award carries a prize of not less than $500. Calls for nominations will be made early in 1998.

The R.M. Johnston medal was awarded in November 1997 to Launceston composer, Professor Peter Sculthorpe, for outstanding contributions to the development of music in Australia. Peter Sculthorpe's use of innovative idioms from the Australian landscape and indigenous peoples, his deep interest in, and use of the special quality and sounds of Japanese and Balinese music enabled his work to reflect a new Australianism.

This was beautifully illustrated in his lecture immediately following the medal award presentation. Peter Sculthorpe's concern for the Tasmanian community was recently expressed in a requiem composed in memory of the Port Arthur Tragedy.



Peter Sculthorpe with his award.
Photo courtesy of the *Mercury*.

Grants to the Society

Council received support from the State Government in the form of a special grant of $3000 towards the cost of the Society's publication programme and, through Arts Tasmania, a grant of $2000 towards the administration and promotion of the Society.

The publication programme was also supported by a grant of $3000 from the University of Tasmania.

The Society acknowledges receipt of these grants with thanks and appreciates the support implied by them.

Library

This year has seen some disruption to Library processes and development due to the anticipated move of the collection to the SciTech Library building as part of the University's research and low-use collections. The cancellation of this move and the associated merger of Sandy Bay campus libraries resulted in a further review of the Morris Miller building and collection arrangements with a decision late in the year to move the Royal Society Collection (and other collections) to level one of the Morris Miller building.

As a result of this decision, which stemmed from the need to use some areas currently occupied by the Royal Society collection for office space, the whole collection was moved to an adjacent area on the same floor during the last weeks of 1997. This temporary location should not affect access and use of the collection for the time it remains there.

Volumes 130 (part 2) and 131 were despatched to exchange partners during the year, again using the updated address labelling system first used in 1996.

A significant increase in the amount of binding was possible and a total of 187 volumes (compare with 34 in 1996) were bound during the year. As in the past, Royal Society binding quotas form part of that allocated to the Morris Miller collection, but some fluctuations in preparation and requirements in other areas made it possible to increase the Royal Society output for the year. The state of binding for the collection remains good, and no significant backlogs of unbound material exists.

The slow, but systematic, cataloguing of library materials into the University Library database continued during the year, but the introduction of a new Library system inevitably slowed down the progress in this and, indeed, all areas. It is still planned to integrate all rare materials onto the database, prior to the reshelving of the rare books with the University's collection in the atmospherically controlled Archives store and the recataloguing of current serials remains a priority.

Although Graeme Rayner remains as the Society's Librarian, the long-term Library Assistant (Carol Freeman) resigned from the University in January this year and was replaced in part by Shane Roberts, who undertakes the day-to-day running of the Royal Society Library and the University Archives. Despite these combined tasks, he remains available in the Library and adjacent areas on a full-time basis. Emilia Ward continued to assist on a daily basis with Library routines and her help is greatly appreciated.

Both Shane and Emilia spent time preparing a Library booklet which should be available in 1998. This booklet outlines the resources of the Library and should prove a valuable guide for members and users until such time as the whole collection is listed on the database.

Statistics for the Library remain subject to the peculiarities associated with an honour system, and some users still forget to sign the register. Loans are always low, due to the photocopying facilities which determine that users copy articles rather than borrow a volume. Visitor/user numbers are, however, significantly higher this year and are as follows: visitors – 303, loans – 45, intercampus/interlibrary loans – 46.

Publications

Volume 131 of the *Papers and Proceedings* was published during August. In it were the Clive Lord Memorial Lecture on "Teresa Hamilton in Tasmania: first-wave feminism in action" by Dr Alison Alexander, together with the Annual Report for 1996 and nine refereed papers. The papers dealt with various aspects of Tasmania, including botany, particularly plant ecology, geology, speleology and zoology. Authors are affiliated with State and Federal departments, the University of Tasmania and the University of South Australia, and one is in private practice.

Mrs Alison Jones acted as sub-editor and Ms June Pongratz prepared the papers for publication. Their considerable assistance is acknowledged with many thanks.

Awards to Students

Two Royal Society Bursaries (financed by the Royal Society and associated Scientific Bodies) were awarded during the year.

The first was awarded to Andrew Job of Rokeby to help him attend the Canada Wide Science Fair in Regina, Saskatchewan. Andrew represented Australia at this event following rigorous testing and selection.

The second Bursary was awarded to Andrew Howell of Legana to attend, as a representative from Australia, the International Youth Science Forum in London.

Andrew Job receiving his bursary from the President of the Royal Society. Photo courtesy of M. de Quincey.

Certificates issued by the examining bodies were presented in December 1997 to Tasmanian students for outstanding performance in national qualifying examinations for admittance to the Rio Tinto Australian Science Olympiad selection processes in biology and chemistry and to the Australian Mathematical Olympic Committee's School of Excellence (see photograph below).

Certificate winners Elizabeth Murchison (left), Caroline Mobsby and William Moase with Deputy Premier Sue Napier and Royal Society of Tasmania Vice-President Dr John Thorne. Photo courtesy of Star Newspapers.

Events in 1997

March 11 — (Annual General Meeting) at Government House, Hobart; "Originally Tasmanian – a brief survey illustrating that Tasmanian creativity is not confined to the Arts" the President.

April 1 — "Jetties in southern Tasmania" Dr Eric Guiler, Sandy Bay.

May 6 — "Species, computing and evolution; ways of looking at marine communities" Professor Craig Johnson, University of Tasmania, Hobart.

June 3 — "Remembering Sir John Franklin" Ms Joan Woodberry, Mt Nelson.

July 1 — "How man-made satellites work, and how they work for mankind" Dr Ian Barton, CSIRO, Hobart.

August 5 — "An introduction to the diversity in form and habitat of Tasmanian ferns" Mr Michael Garrett, Bicheno.

September 2 — "*Armillaria* in the Botanical Gardens" Dr David Bedford, Royal Tasmanian Botanical Gardens, Hobart.

October 7 — "Marine Pests and their management in Australian waters" Dr Chad Hewitt, Dr Gustaaf Hallegraeff, Mr Craig Proctor, Mr Jeff Ross and Dr Louise Goggin, Dr Ron Thresher in the chair; CSIRO and University of Tasmania, Hobart.

November 4 — "Post-Colonial in contemporary cultural theory and art making" Mr David Hansen, Tasmanian Museum and Art Gallery.

November 28 — Presentation by the President of the R.M. Johnson Medal to Professor Peter Sculthorpe, Sydney; followed by Professor Sculthorpe speaking on the influences on his music. A Christmas dinner followed.

December 2 — *Land of sorrow, land of honey – the life of Judah Solomon.* Dr Hamish Maxwell-Stewart University of Tasmania.

Northern Branch

Branch Council

Chairman	Professor Campbell Macknight
Vice-Chairman	Ms Judith Hollingworth
Past Chairman	Mr Elvin Fist
Honorary Secretary	Mr Chris Tassell
Honorary Treasurer	Mrs Doreen Girvan
Committee	Mrs Christine Beswick
	Mrs Mary Cameron
	Mr Brian East
	Mr David Hannan

The Council met four times in 1997

Meetings and Lectures

February 7 — "When all is said & done, timber is timber" Professor John Webster, University of Tasmania, Newnham.

March 7 — Annual General Meeting chaired by the President, His Excellency Sir Guy Green, AC, KBE; "From disaster to display: 200 years of the Sydney Cove".

April 11 — "Acacias of Australia" Mr John Simmons

May 2 — "Woolmers Estate" Mr Richard Archer.

June 6 — Meeting cancelled to allow members to attend the Dr Pugh Oration.

July 4 — "Air pollution environmental health and respiratory diseases. Launceston and Upper Tamar" Dr Lloyd Lyons.

August 1 — "Writing the history of the Launceston Church Grammar School" Dr Alison Alexander, Hobart.

September 5 — "From summit to the ice sheet to the Southern Ocean: examples of the role of Antarctica in global process from recent studies in the Lambert Glacier/Amery Ice Shelf/Prydz region" Dr Ian Allison, University of Tasmania, Hobart.

October 9 — Three students from the University of Tasmania, Newnham
Mr Nial Stewart, Department of Aquaculture
Mr Telis Dimitrakoppulos, Department of Physical Sciences
Ms Lucy Di Benedetta, Department of Physical Sciences

November 7 — "Tasmanian Earthworms" Dr Rob Blackmore, Queen Victoria Museum.

December 5 — Members night
"Some research revisited" Mr Stan Payne.
"Propagation of potatoes for Tasmanian industry" Mr Bruce Beattie
"Images of Europe" Mr Allan Orr.

Excursions

May 3 — Excursion to Woolmers Estate, Longford

Other Activities

July 2 — Presentation of Royal Society Bursary to Andrew Howell.

Nominees to other Bodies

Tasmanian Museum and Art Gallery

Council elected Professor J. Reid and Dr A.V. Brown to serve on the Board of Trustees for 1997. These Trustees arranged for Ms P. Sabine, Director, to report on the year's activities as follows:

1997 was another eventful year for the Tasmanian Museum and Art Gallery marked by both triumphs and tragedy.

Trustees

Chairman of Trustees Alan Blow OAM, QC concluded his period of appointment in April after almost seven years as a Trustee and Dr Tony Brown was elected Chairman in his place for the remainder of 1997. The Governor's re-appointees to the Board to April 1999 were Professor Emeritus Coleman O'Flaherty, Mrs Jill Freeman and Mrs Jeannie Taranto; Mr Euan Hills was appointed to fill the vacancy left by Alan Blow's retirement. The Hobart City Council representative is Alderman Ian Malcolm and Royal Society of Tasmania Trustees are Dr Tony Brown and Professor Jim Reid.

The Trustees and staff of the TMAG would like to congratulate Alan Blow on his very successful Chairmanship ot the Board. He provided the timely guidance and encouragement needed for the TMAG to enter a new and ambitious era of change. The changes were often difficult and unsettling and included long-term strategic planning, staff restructuring, facilities redevelopment, computerisation of services and expansion in the arena of public programs, collections management, research and community profile.

It is, however, with great sadness that I must report the unexpected death of the Curator of Vertebrate Zoology, Phil Andrews, in early February after a short illness Phil had been a member of staff at the TMAG since 1965 and a long-term member of the Royal Society of Tasmania — the Society having published many of his scientific papers. His extensive knowledge of the vertebrate fauna of Tasmania and the Applied Sciences collections at the TMAG have been sadly missed.

Staff

The Director, Patricia Sabine, was named Telstra Tasmanian Businesswoman of the Year 1997. This award gained further favourable publicity for the Tasmanian Museum and Art Gallery through articles in *Business Review Weekly* and *The Australian.*

Curator–Invertebrate Zoology, Roger Buttermore, was awarded a Churchill Fellowship to continue his work on the introduced species *Bombus bombus.* He will be travelling overseas in 1998.

Curator–Phanerogamic Botany, Andrew Rozefelds, was awarded his Doctorate in Philosophy by the University of Melbourne and was elected to the Council of the Royal Society of Tasmania. He was also awarded a Savings and Loans Public Service Fellowship to establish contacts and review the scientific displays of several North American museums. In Canada he presented two papers to the 1997 American Botanical Society meeting

New appointments to the staff in 1997 include Tony Brown, Trainee Collections Management Officer, Indigenous Cultures Collection, appointed in October, Jodie Murray as Assistant Curator–Decorative Arts, and Dr David Pemberton, who will commence work in 1998 as Curator–Vertebrate Zoology.

The regular program of tours by volunteer guides to both the general areas of the TMAG and to special exhibitions has been very effective and well patronised. The value of volunteer assistance at the TMAG has been assessed at $300 000 per annum.

Considerable financial support has been received in 1997 from the Hobart City Council, through subsidising the rent of the City Hall for "Whales" and through the provision of a one-off grant towards the cost of employing a Public relations/Fund raising/Development Officer, Peter West.

Facilities Management

The Customs House has been operating effectively with "Port Adventure" in the Children's Discovery Centre and with the Royal Society's Lecture Theatre in regular use. Progress towards the establishment of a cafe was curtailed in 1997 due to unexpected changes in circumstances and it is now proposed to open in autumn 1998.

Further work continued on the upgrading of the Moonah Store Workshops, the Private Secretary's residence and the security, fire detection system and computer network for the whole TMAG complex.

Public Programmes

The 1997 exhibition program was notable for its variety with a strong emphasis in the latter half of the year on things maritime leading up to the International Year of the Ocean.

Audience Development

Record attendances peaked at 198 000 as a result of high profile exhibitions such as *Tom Roberts as you have never seen him before* and MIM presents *Whales: Giants of the Deep* (48 000), supported by the extensive in-kind sponsorship provided by *The Mercury* and the Southern Cross Television Network.

Exhibitions

Major exhibitions included the following: Mazda presents *Tom Roberts as you've never seen him before,* from Art Exhibitions Australia; *Eyes on the Ball: Images of Australian Rules Football,* City of Waverley; *Apples from Oz: Marketing to the Empire and Beyond,* TMAG; *Two Sisters and other Stories: Phyllis and Joan Pitman,* TMAG; *Thar She Blows: Whales and Whaling in Tasmania,* TMAG; *Made of Glass,* TMAG; *Impressions: Australian in Vietnam,* Australian War Memorial; *Peter Rosson: Survey Exhibition* 1975–95, TMAG; *Sea: Maritime Treasures from the TMAG,* TMAG; *Sydney Harbour and David Moore 50 Years of Photography,* Gavin Wilson & Associates; *Surfabout,* MWA

As well as showings from the collection, two small case shows, *Cannabis in Tasmania* and *Argonauts: Graceful sailors in boats of shell,* received well-deserved praise and will travel to other venues. *Argonauts* has been endorsed by SOCOG as an official Sydney Olympics exhibition.

School holiday programs and special events such as "Frog Week" continue to attract large numbers of participants.

Research

The research program continued with The Herbarium collecting flora specimens for the AMRAD contract.

Information Services Curator Alison Melrose has ensured a presence for the TMAG on the Internet through

DECCD's Cultural Web page. Computerisation of collection records continued with the assistance of volunteers and jobskills staff. The assistance of volunteers has been vital but the TMAG would see significant benefits with an increase in the hours of the professional staff, particularly in the area of Information Services, scientific preparation, conservation of works on paper and textiles, and assistant curatorships in Art, History and Applied Science.

Progress continues to be made with physical infrastructure, and public programme development. The next five years should see major attention turned to the collection especially in the area of long-term displays of the natural history collections, research and publications about the collection. Fund-raising has become a major issue, in order to ensure that collections can be adequately preserved and developed. The second stage of the ten-year redevelopment should begin in the 1998–99 financial year. The staff of the TMAG are to be commended for an excellent year's work.

Royal Tasmanian Botanical Gardens

Dr M. Brown was nominated to serve on the Board of Trustees for 1997. The Director, Dr Bedford, makes the following report:

Objectives

- To increase knowledge, awareness and understanding about the economic, social and ecological value of plants.
- To conduct research and conservation programs on the Tasmanian and allied floras.
- To manage, care for, document and further develop the Gardens sites and collections of living and preserved plants and ancillary materials.

Achievements

Visitation levels to the Gardens increased to 346 200 visits, an increase of 19 200 over the previous year.

The greatest challenge facing the Gardens has been through plant diseases. As well as discovering a number of additional areas affected by *Phytophthora cinnamomi*, the significant increase in the area affected by *Armillaria luteobubalina* represents a major threat to the survival of the Gardens in its current form. The affected area covered over one and a half hectares and more than 80 trees have been lost.

An extremely successful public appeal for funding (*The Mercury* Save the Gardens Appeal) raised $220 000. The Appeal was run by an independent committee chaired by Peter Cundall. Generous donors included the Hobart City Council ($25 000) the State Government ($22 500), The Trust Bank Foundation ($20 000), ANM ($5000), other local government bodies, corporations and members of the public. It was particularly pleasing to see the very high level of support from the public, who donated nearly two-thirds of the total raised in small donations. Support from *The Mercury* newspaper was critical to the success of the Appeal, and was assisted by support from other media including *WIN TV* and *ABC Radio 7ZR*.

The funds available from the Appeal have allowed considerable progress to be made in fighting the fungus. Funds were used for the very successful seven-week secondment of Dr Brett Summerell from the Royal Botanic Gardens Sydney to recommend pest and disease management strategies within the Gardens. The appointment of Dr Frank Hay to the role of Plant Protection Officer was also an important step in the gardens disease management strategy. A large excavation from the main lawn area removed significant amounts of *Armillaria* infected wood. Work on prevention of the spread of *Phytophthora* also continued.

Slow progress has been made on further development of an Enterprise Development Agreement being developed co-operatively with all staff and unions. The strategic and action plans have led to the development of much closer liaison between sections of staff and to improved communications and planning. The relocation of horticultural management, community education and training and administration staff into the historic Superintendent's cottage has made a significant improvement in organisation.

In conjunction with scientists from Parks and Wildlife, the RTBG plays an important role in the collection, propagation and growing of Tasmania's rare and threatened flora. The RTBG has had an on going involvement in nine Rare and Threatened plant projects during the year, as well as supplying the facilities for two Parks and Wildlife research projects.

Horticultural advice and assistance and flora conservation work have been provided throughout the state, including a continuing involvement with plant conservation programs at the TEMCO site and the northern-based community group, the Understorey Network.

The collection of Macquarie Island plants has been considerably expanded through a co-operative program with the University of Queensland scientists studying vegetation ecology and climate change. In addition to the previous grants totalling $88 000 from the Australian Antarctic Foundation, sponsorship of $10 000 was committed by the Friends of the Royal Tasmanian Botanical Gardens Inc., $5000 from ComputerLand, $1000 from J.B.Were and Sons, as well as amounts from private sponsors. The design brief for the Australian Antarctic Foundation Subantarctic Plant House and proposed landscape were finalised and architects Forward Viney Woollan and a team of consultants prepared plans and engineering specifications. Planning approval was obtained from Hobart City Council in June.

The Chinese plants section, generously sponsored by ComputerLand and the Friends of the Royal Tasmanian Botanical Gardens Inc., neared completion during the year. The majority of the paths and hard landscaping have been completed, and about two-thirds of the area planted.

A detailed application was made for Tasmanian Government funding for a visitor interpretation centre. This included completing the Project Initiation Process with a value management study. Funds were applied for over 1997/98 and 1998/99.

Development of a master plan for the RTBG was slower than expected, owing to the demands of the public appeal and the disease management. However, basic maps of the Gardens were prepared with assistance from the Land Information Bureau and the University of Tasmania Department of Surveying and Spatial Information Science. In addition, the surveys of the state and needs of the gardens and initial discussion papers began the detailed planning process.

Looking Ahead

Through the coming year the Gardens plan to

- maintain visitation levels at around 350 000;
- manage and attempt to control the fungal infestation;
- complete the Chinese Plants section and the Macquarie Island greenhouse prototype;
- further develop a master plan for the RTBG;
- proceed with development of a visitor interpretation centre if funding is available.

Acknowledgements

The council is grateful for help generously given by many individuals and organisations. The referees, lecturers, the Government of Tasmania, the University of Tasmania, Arts Tasmania, the North West Centre of the University at Burnie, the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery are particularly thanked for their support and co-operation. Thanks also are extended to the CSIRO for providing facilities for Council meetings, General Meetings and catering for the Christmas Function.

John Thorne
Vice-President
12 February 1998

Michael Readett
Hon. Secretary

ROYAL SOCIETY OF TASMANIA – NORTHERN BRANCH

The statements for the Northern Branch were not examined by the Auditors but are included here for information.

Statements of Receipts and Expenditure for Year ended 31 December 1997

Receipts

Subscriptions		70.00
Suppers		0.00
Grant 1997		2500.00
Grant 1998		2500.00
Bank interest		3.08
		5073.08
Balance at Trust Bank 1.1.97	114.65	
Less unpresented cheque (361)	30.00	
		84.65
		5157.73

Expenditure

Subscriptions to RST (Hobart)	70.00
Printing and stationery	232.80
Theatrette hire	0.00
Postage	346.50
Post box	44.00
Secretarial	955.00
Bank charges	6.94
Suppers	57.90
Travelling	0.00
Miscellaneous	60.00
Unknown charges	2.72
	1775.86
Bank balance 31.12.97	3381.87
	5157.73

D.M. Girvan
Hon. Treasurer (Northern Branch)

Reconciliation Statement 1997

Credit balance as per Bank Statement 31.12.97			3381.87
Credit Balance at 1.1.97	114.65		
Less unpresented cheque (699361)	30.00		
		84.65	
Receipts for year		5073.08	
		5157.73	
Expenditure for year	1773.14		
Plus unknowns/bank chgs	2.72		
		1775.86	
Debit Balance			3381.87

ROYAL SOCIETY OF TASMANIA

Statement of Receipts and Payments for the Year ending 31 December 1997

	1997 $	1996 $
Balance 1 January 1997 (as audited for 1996)	34 767.42	40 134.07
Add Receipts		
Subscriptions	11 170.00	11 998.00
Publications		
Regular sales	4 210.70	2 031.95
Rare Book sale	11 620.00	1 550.00
ANZAAS related	2 931.64	7 535.00
	18 762.34	11 116.95
Donations		
Per symposia	-	1 350.00
Foundation	1 057.00	1 673.00
	1 057.00	3 023.00
Interest	223.66	971.79
Government grant	8 000.00	5 000.00
Meeting funds		
Various functions	3 268.00	5 111.20
Sundry	343.22	628.80
	3 611.22	5 740.00
Student Bursary Collections	1 100.00	
Total Receipts	43 924.22	37 849.74
Deduct Payments		
Subscriptions	3 818.19	3 618.11
Printing & stationery	2 238.60	2 336.00
Postal costs	2 977.04	2 223.05
Meetings Attendants' fees	1 120.00	1 124.10
Functions	2 746.40	2 796.85
Bank charges	174.68	95.82
Publication costs	13 559.33	10 968.43
Northern Branch	5 000.00	1 910.00
Secretarial services	3 480.00	3 360.00
Administration/insurances	728.18	798.45
Sundry		
Repairs	126.55	100.00
ANZAAS	1 147.50	
Other	433.00	369.00
Student support	1 000.00	700.00
Foundation/society advertising/promotion	2 034.53	2 020.58
Funds transfer	13 668.00	8 410.00
Sundry	278.30	(44.00)
Total Expenditure	54 530.30	43 216.39
Cash at Bank Balance 31st December, 1997	24 161.34	34 767.42

Statement for the Royal Society Foundation Trust Fund for the Year ending 31 December 1997

Foundation approved by membership and Council 1995. Officially opened November 1995.

The Royal Society Foundation Trust Fund replaces all previous Trust and Memorial Funds.

Funds held by Perpetual Trustees (as managers)	
Funds held at 31 December 1996	32 404.10
Capital deposits during 1997	13 668.00
Total capital at 31 December 1997	46 072.10
Interest:	
Interest derived from capital fund	2 825.36
Interest derived on interest fund	177.67
Previous interest on fund	2 693.59
Total funds in Trust at 31 December 1997	51 768.72
Other information:	
Funds transferred in January 1998	1 240.10
Estimated value of Trust at date of AGM	53 500.00

Accumulation Account for the Period 1 January to 31 December 1997

Balance at 1 January 1997	$57 022.65
Balance adjusted prev uncashed chqs ($87+$285)	57 394.65
Current outstanding ($1147.50)	56 247.15
Cash items:	
Add increases at bank	-9 830.58
Sub total at 31 December 1997	46 416.57
Asset items:	
Add new assets as per statement of payments	0.00
New total for 1997	46 417.57

Balance Sheet as at 31 December 1997

1996 $		1997 $
57 022.65	Accumulated Funds	46 416.57
35 097.69	Foundation Funds	51 768.72
7 004.77	Life Membership Fund	7 004.77
99 125.11		105 190.06
	Represented by	
34 767.42	General Account	24 161.34
35 097.69	Foundation Trust Perpetual Trust	51 768.72
15 000.00	Library (value for insure)	15 000.00
5 000.00	Publications (est. realisable value)	5 000.00
5 600.00	Medals (at sell prices)	5 600.00
3 660.00	New Assets	3 660.00
99 125.11		105 190.06

ROYAL SOCIETY OF TASMANIA

Notes To and Forming Part of the Accounts for the Year ended 31 December 1997

Note 1 - Statement of Accounting Policies
This is not a general purpose financial report. It is a special purpose report prepared to meet the requirements of members of the Society.

The Society is of the type identified in Statement of Accounting Concepts 1 as a non-reporting entity. No regard has been paid to other Accounting Standards in the preparation of this report.

The accounts have been prepared on a cash basis from historical cost records, except where stated otherwise.

Income Tax
The Association is an exempt body for income tax purposes under Section 23(g)(iii) of the Income Tax Assessment Act.

Note 2 - Valuation and Existence of Assets
The insurance valuation for the library is only for petty theft. The actual value (in terms of net realisable value, cost, or market value) is not determinable. Therefore, the insured value of the library is not an accurate depiction of its value to the Society.

A number of paintings of considerable value exist that are the property of the Society. There are also a number of paintings which may be the property of the Society. These assets have been omitted from the Balance Sheet as their value cannot be accurately determined.

Independent Audit Report to the members of the Royal Society of Tasmania

Scope
We have audited the attached accounts of the Royal Society of Tasmania for the year ended 31st December, 1997. The Society's office bearers are responsible for the preparation and presentation of the accounts and the information they contain. We have conducted an independent audit of these accounts in order to express an opinion on them to the members of the Society.

Our audit has been conducted in accordance with Australian Auditing Standards to provide reasonable assurance as to whether the accounts are free of material misstatement. Our procedures included examination, on a test basis, of evidence supporting the amounts and other disclosures in the accounts, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion as to whether, in all material respects, the accounts are presented fairly.

As detailed in Note 1 to the Accounts, the Society is not a reporting entity because no users exist who are unable to command the preparation of reports tailored so as to satisfy specifically all of their information needs, and these Accounts are therefore "Special Purpose Financial Reports" that have been prepared solely to meet the requirements of the members of the Society.

The audit opinion expressed in this report has been formed on the above basis.

Audit Opinion
In our opinion, the accounts of the Royal Society of Tasmania are properly drawn up so as to present fairly the Society's state of affairs as at 31st December, 1997 and of its result for the year ended on that date.

DELOITTE TOUCHE TOHMATSU

L.T. COX
Partner
Chartered Accountant

Hobart, 10th March 1998

AGE PROFILE OF CARP (*CYPRINUS CARPIO* L.) IN LAKE CRESCENT, TASMANIA

by Lorenzo Vilizzi and Keith F. Walker

(with five tables, four text-figures and one plate)

VILIZZI, L. & WALKER, K.F., 1998 (31:xii): Age profile of carp (*Cyprinus carpio* L.) in Lake Crescent, Tasmania. *Pap. Proc. R. Soc. Tasm.* 132: 1–8. ISSN 0080–4703. Department of Environmental Sciences, University of Hertfordshire, College Lane, Hatfield, Hertfordshire AL10 9AB, UK (LV, formerly University of Adelaide); Cooperative Research Centre for Freshwater Ecology and Department of Zoology, University of Adelaide, South Australia, Australia 5005 (KFW).

Carp is an exotic, benthivorous fish implicated in degradation of wetlands throughout southeastern mainland Australia. In the present study, the age profile of a stock in Lake Crescent, Tasmania, was determined by length-frequency analysis and inspection of annulus patterns in whole and sectioned otoliths. Marginal increment analysis was attempted to validate age assessments for fish captured in 1995 and 1996. The available samples limited formal validation to age group III+, but it is clear that the January 1993 year-class was dominant among other fish of 1–6 years of age. Future monitoring should include monthly observations of age structure, reproduction and recruitment.

Key Words: fish, Cyprinidae, exotic species, otolith, validation, Lake Crescent, Lake Sorell, Tasmania.

INTRODUCTION

Lake Crescent (57 km^2) is at 820 m altitude on the eastern edge of the Central Plateau in Tasmania and drains into the Clyde River. The lake supports a very minor fishery for the native short-finned eel, *Anguilla australis*, and there is also a recreational fishery for the exotic brown trout, *Salmo trutta*, and rainbow trout, *Oncorhyncus mykiss*. An endemic galaxiid, *Galaxias auratus*, is also abundant (Fulton 1990). Another exotic fish, the European carp, *Cyprinus carpio* L., was discovered in 1992. This was the first report of this species from Tasmania since a population was found (and later eradicated) near Burnie in the early 1970s.

Population age data are helpful to assess the suitability of control methods like poisoning, drawdown and intensive fishing (Roberts & Tilzey 1997), and to allow determination of recruitment and year-class strength (Mann 1991). In cyprinids, scales and, to a lesser extent, opercular bones are used widely as indicators of age (Mann 1991), and otoliths (especially lapilli) also have been employed (e.g. Backe-Hansen 1982, Mills 1988, Mina 1989, O'Maoileidigh & Bracken 1989). In carp there are several potentially suitable structures (Vilizzi & Walker 1995). For example, English (1952) and Rehder (1959) found scales and opercular bones to be good indicators of age and growth, and Wichers (1976) and Bishai & Labib (1978) judged fin rays and vertebrae, respectively, to be most convenient and reliable. No one method, however, has proved consistently effective.

The present study determined the age profile of the Lake Crescent carp stock based on length-frequency distributions and interpretation of otolith patterns, using techniques developed for carp in the River Murray, South Australia (Vilizzi & Walker 1998; Vilizzi *et al.* 1998).

MATERIALS AND METHODS

Samples and Preparation

An aggregate sample of 333 fish was provided by the Inland Fisheries Commission, obtained by electrofishing and netting in February–March 1995, September–November 1995 and January–February 1996. Four of the fish came from Lake Sorell (catchment 103 km^2), which drains into Lake Crescent via a small artificial channel (table 1). The fish were sexed, when possible, and fork length (FL, ± 1·0 mm) and weight (W, ± 1·0 g) determined. Otoliths (asterisci) were recovered from 189 fish. In total 75 fish were interpreted for age from whole otoliths, 58 from sectioned otoliths, and 56 from both.

Whole otoliths were viewed immersed in water, with the distal side facing the observer and the ventral margin up, using a dissecting microscope (20–40X) and a dark

TABLE 1
Sampling of carp in Tasmania

Sampling site	Date*	*n*†
Crescent	1.ii.1995	10
Crescent	2.ii.1995	22
Crescent	7.ii.1995	7
Crescent	8.ii.1995	1
Crescent	15.ii.1995	12
Crescent	22.ii.1995	50
Crescent	4.iii.1995	26
Sorell	4.iii.1995	4
Crescent	14.iii.1995	20
Crescent	22.iii.1995	56
Crescent	28.iii.1995	18
Crescent	29.iii.1995	2
Crescent	27.ix.1995	13
Crescent	5.x.1995	8
Crescent	9.xi.1995	2
Crescent	23.xi.1995	20
Crescent	6.i.1996	42
Crescent	14.ii.1996	1
Crescent	21.ii.1996	19

* Date of collection of carp in Tasmania.
† Indicates the sample size and number of fish interpreted for age (whole and sectioned otoliths).

background (reflected oblique light). Under these conditions, an annulus was defined as a transition between a translucent (dark) and an opaque (light) zone. Annuli were counted on the distal side of the otolith, along the antero-dorsal region, at the level of the dorsal spike, a projection analogous to the antirostrum of the non-otophysan teleost sagitta (Pannella 1980) (pl. 1).

When possible, the left otolith of each pair was embedded in clear polyester resin in 8 mm thick blocks (about 62 mm^2), each containing 10–14 otoliths (depending on their size) with their nuclei carefully aligned. Three successive transverse sections (0·4–0·5 mm) were cut through the nucleus, using a low-speed lapidary saw (Augustine & Kenchington 1987). Sections were polished with 1200-grit carborundum paper to enhance the visibility of the zones. The sections were examined under the same lighting conditions used for analysis of whole otoliths (transmitted light proved unsatisfactory).

Validation and Age Adjustment

Validation was based on marginal increment analysis (MIA) (Bagenal & Tesch 1978), including marginal increment ratio analysis (MIRA) and edge type analysis (ETA) (Haas & Recksiek 1995), with regard for the "edge interpretation problem" (Francis *et al.* 1992). MIA elucidates relationships between the spatial patterns seen in calcified structures and the temporal patterns caused by environmental changes. The marginal increment ratio (MIR) was calculated as

$$MIR = [(NE - NLA) / (NLA - NSA)] \times 100$$

where NE = distance from nucleus to outer edge, NLA = distance from nucleus to last-formed annulus, and NSA = distance from nucleus to second-last-formed annulus. Where there was only one annulus the denominator becomes the distance from nucleus to annulus. The edges of otoliths were recorded as "opaque" or "translucent", and, for the edge type analysis, the last-formed annulus was judged as C ("close") (MIR 50%), Z (other) (50% < MIR < 75%) or N ("now due") (MIR 75%), using a technique modified after Anderson *et al.* (1992a, b).

Age adjustments allowing for the time of capture and the relative growth of whole and sectioned otoliths followed the procedure of Vilizzi & Walker (1998), with minor modifications. January 1 was taken as the nominal birth-date of each annual cohort. This date corresponded to the onset of a protracted period of mean water temperatures exceeding 15°C, the minimal spawning threshold for carp

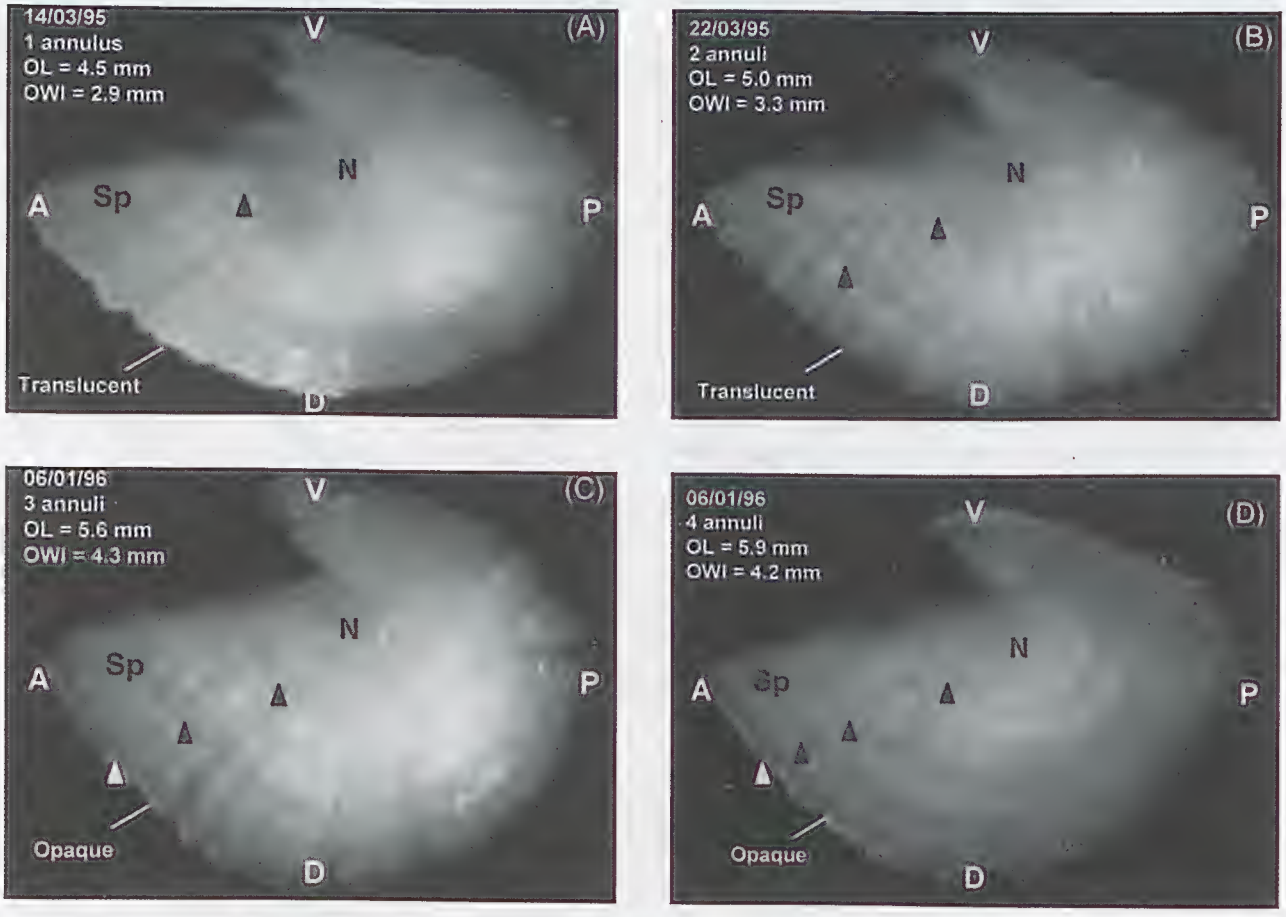


PLATE 1

Otoliths (asterisci) from Lake Crescent carp, Tasmania. Under reflected oblique light on a dark background an annulus is a transition between a translucent (dark) and an opaque (light) zone, here indicated with a triangle. The edge type (i.e. opaque or translucent), the date of capture of the fish and the number of annuli are reported. Sp, *antero-dorsal spike;* A, *anterior edge;* P, *posterior edge;* D, *dorsal edge;* V, *ventral edge;* N, *nucleus;* OL, *otolith length;* OWI, *otolith width. (A) 1 annulus, translucent edge, late summer; (B) 2 annuli, translucent edge, late summer; (C) 3 annuli, newly-formed opaque zone, summer; (D) 4 annuli, opaque edge, summer.*

(Sarig 1966, Guha & Mukherjee 1991). The age of a fish with MIR 50% (new annulus forming), caught in November or December, was reduced by one year, regardless of the number of annuli. Similarly, the apparent age of a fish caught in January with MIR 75% (new annulus due) was increased by one year regardless of the number of annuli. In February, the age of a fish with more than one annulus but about to form a new annulus (MIR 75%) was increased by one year and, in March, the same adjustment was applied to fish with more than two annuli and MIR 75%. Adjustments were not needed for fish caught from April to October (table 2).

Analysis

Length-frequency data and MIA were used to estimate the age composition of the stock. Fork lengths for the three different catches were compared by one-way ANOVA, and mean annulus distances from the nucleus in otoliths of carp from Lakes Crescent and Sorell, and from the River Murray in South Australia (Vilizzi & Walker 1998) were compared by two-way ANOVA (sampling location x number of annuli). Differences between means were evaluated using Tukey's HSD test for unequal sample sizes (Spjotvoll & Stoline 1973). Comparisons of growth in males and females, analyses of residuals and validation of parametric methods followed Vilizzi & Walker (1998).

RESULTS

Length-Frequency Analysis

Length-frequency distributions for each of the three subsamples were approximately uni-modal. ANOVA and *post hoc* comparisons indicated no significant difference in FL in 1995 (fig. 1A, B), but the mean FL for the 1996 catch was higher than for either catch in 1995 ($P < 0{\cdot}001$) (fig. 1C).

TABLE 2
Adjustments to annulus counts* for carp in Lakes Crescent and Sorell, Tasmania

Month of capture	Annuli†	MIR‡ (%)	Estimated age (y)
Jan		75	Annuli + 1
Feb	1		1
	2	75	Annuli + 1
Mar	2		Annuli
	3	75	Annuli + 1
Apr–Oct			Annuli
Nov–Dec		50	Annuli – 1

* Based on a nominal birth-date of 1 January for each annual cohort.
† Number of annuli counted on the calcified structure.
‡ MIR: marginal increment ratio

Interpretability of Otoliths

Three (2·3%) of the 131 whole otoliths and 21 (18·4%) of the 114 sectioned otoliths were discarded as "uninterpretable". Interpretability was significantly lower for sectioned otoliths ($\chi^2 = 17{\cdot}95$, $P < 0{\cdot}001$).

Validation of Annulus Counts

As comparisons of whole and sectioned otoliths showed no differences in the time of annulus formation and edge characteristics, data for whole otoliths only are considered below. In the following, therefore, "otolith" may be taken to mean either whole or sectioned preparations.

In otoliths with two annuli, MIR remained high throughout the year, peaking in January (fig. 2A). In otoliths with three annuli, a decline in MIR was visible through January (15·5%) and February (26·5%); this rose sharply in March and decreased toward the end of the year (fig. 2B). When annulus groups 1–5 were pooled, a different trend

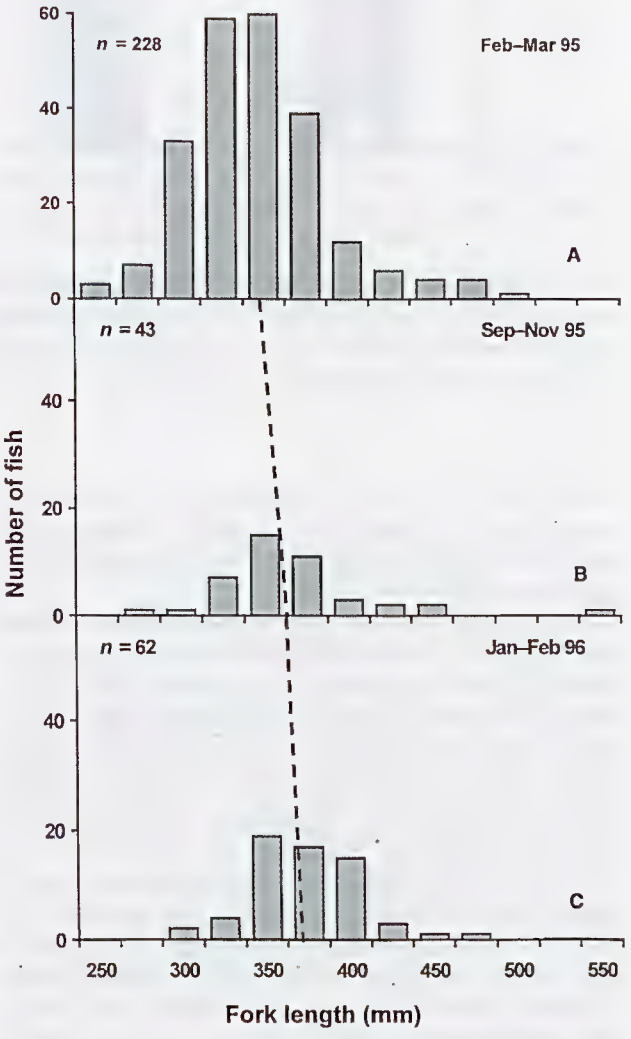


FIG. 1 — Length-frequency distributions of carp from Lakes Crescent and Sorell, Tasmania. Mean fork length values for each sub-sample are joined by a broken line. (A) Combined data for February–March 1995, (B) September–November 1995, (C) January–February 1996

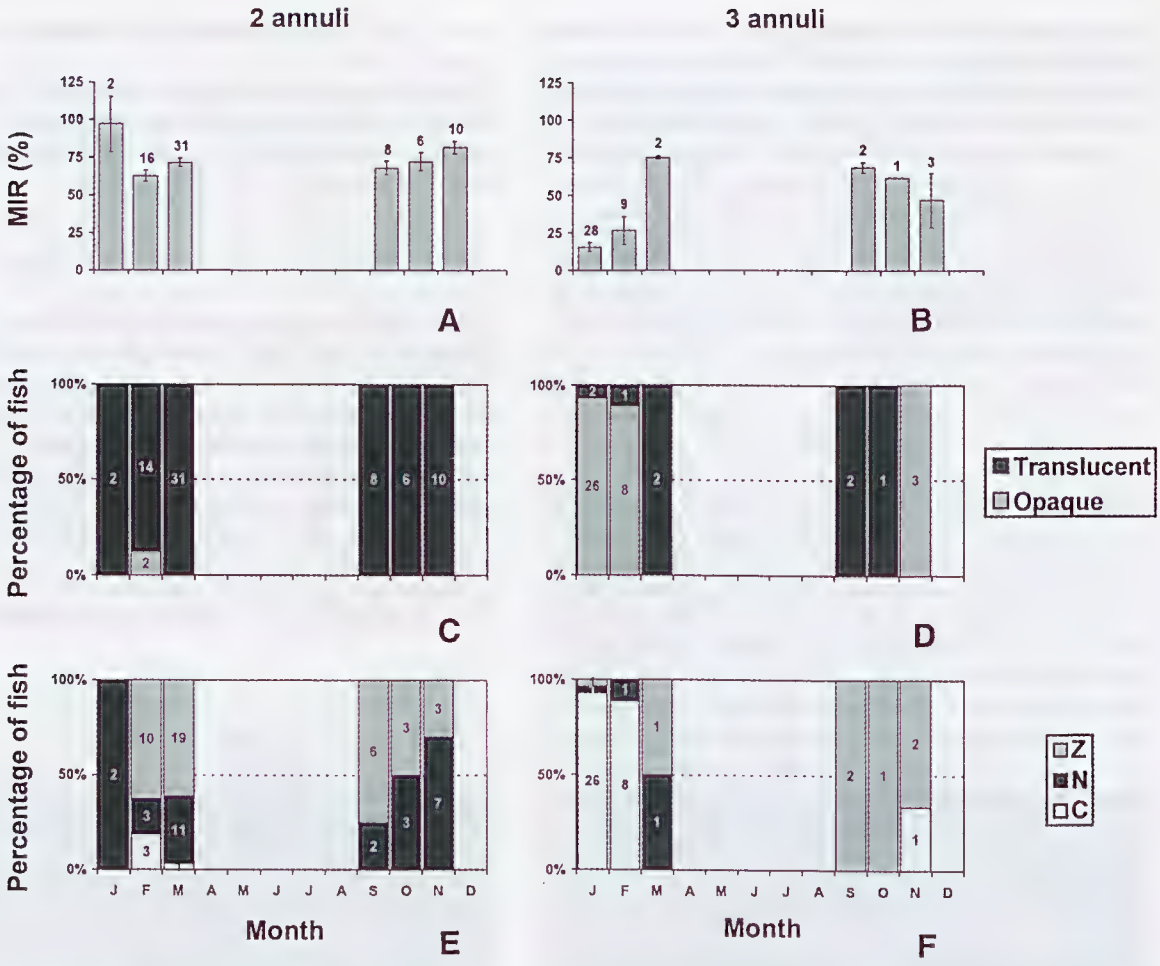


FIG. 2 — Marginal increment analysis of whole otoliths from carp in Lakes Crescent and Sorell, Tasmania. Data for 2 (A, C, E) and 3 (B, D, F) annuli are shown: (A, B) mean monthly values (± SE) of the marginal increment ratio (MIR), as a percentage of the previous increment, (C, D) percentage of fish having otoliths with an opaque or a translucent edge (under transmitted light), (E, F) percentage of fish scored as C *(MIR 50%),* Z *(25% < MIR < 75%), or* N *(MIR 75%).*

was observed. A decline in MIR was apparent in January, when it fell to 25·9%. This increased in February and remained high in November (74·0%), one month before the nominal birth-date (fig. 3A).

Otoliths with two annuli almost always had a translucent edge (fig. 2C), while newly-formed opaque edges were especially common in carp with three annuli captured in January (when most specimens were caught) (fig. 2D). In pooled annulus groups, the percentage of otoliths with an opaque edge was high in January and February but markedly lower in March, when most had a translucent margin. Translucent margins were observed also in fish caught in September–November (fig. 3B).

In annulus group 2, there were few otoliths with type C edges, observed in February and March. This is unexpected, given the distribution of edge types (fig. 2E). A pattern comparable to that noted for MIR and ETA was apparent in annulus group 3, although type Z rather than type N edges predominated in early spring (fig. 2F). In pooled annulus groups, type C otoliths were more abundant in January and February, and the proportions of type N and Z edges increased in November and March–September, respectively (fig. 3C).

Annulus Distance

The mean annulus distance from the nucleus in whole (1–6 annuli) and sectioned otoliths (1–4 annuli) increased progressively, supporting the suggestion that ages estimated from annulus counts did reflect true ages (fig. 4A, B). The mean distance from the nucleus of the first three annuli in whole otoliths from River Murray carp was significantly less than that from Lakes Crescent and Sorell ($P < 0{\cdot}001$) and, as would be expected, there were significant differences among the mean distances from the nucleus of the first three annuli ($P < 0{\cdot}001$) (table 3).

Length–Weight Relationships

The lengths and weights of juveniles, males and females are summarised in table 4. Estimated ages were based on whole or sectioned otoliths and, when both were available for one specimen, the whole otolith was arbitrarily used. Length–weight relationships were modelled for all aged fish (pooled sexes and juveniles). Growth parameters are shown in table 5.

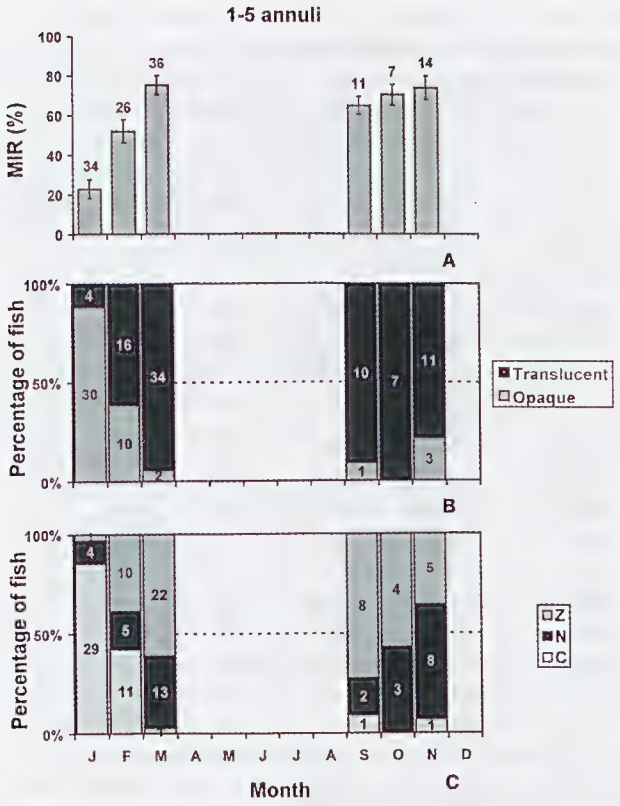


FIG. 3 — Marginal increment analysis of whole otoliths from carp in Lakes Crescent and Sorell, Tasmania (pooled annulus groups only): (A) mean monthly values (± SE) of the marginal increment ratio (MIR), as a percentage of the previous increment; (B) percentage of fish having otoliths with an opaque or a translucent edge (under transmitted light); (C) percentage of fish scored as C *(MIR 50%),* Z *(25% < MIR < 75%), or* N *(MIR 75%).*

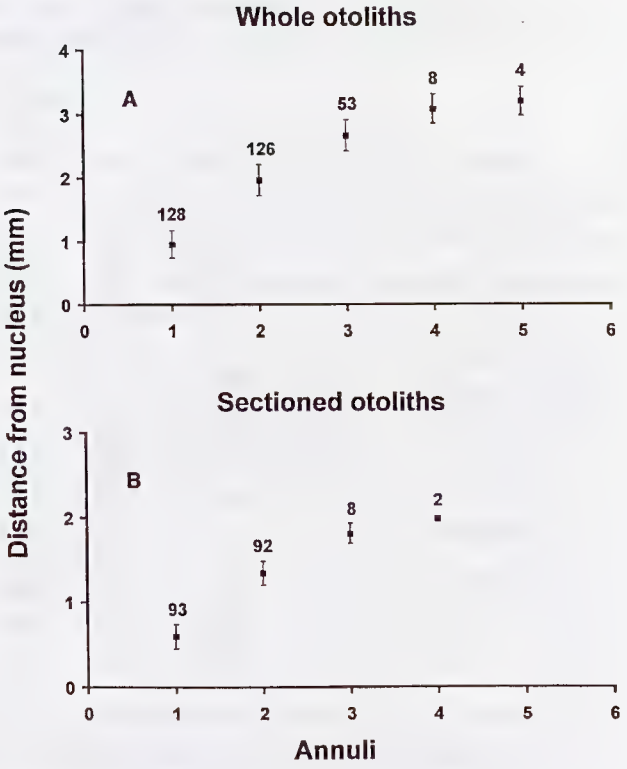


FIG. 4 — Mean annulus distance from the nucleus (± SD) in carp otoliths from Lakes Crescent and Sorell, Tasmania. Annulus counts are based on the corresponding structure. (A) Whole otoliths; (B) sectioned otoliths.

TABLE 3
Distance of annulus from nucleus in whole otoliths compared for carp in two states

	Annulus distance from nucleus (mm)									
	Lakes Crescent and Sorell, Tasmania					River Murray, South Australia				
Annulus	*n*	Mean	± SE	Min	Max	*n*	Mean	± SE	Min	Max
1	128	0·947	0·019	0·56	1·83	417	1·145	0·014	0·51	2·26
2	126	1·966	0·022	1·48	2·60	367	2·260	0·023	1·09	3·50
3	53	2·664	0·034	2·01	3·15	358	2·818	0·026	1·42	4·02
4	8	3·078	0·081	2·71	3·38	301	3·284	0·030	1·82	4·47
5	4	3·200	0·112	2·94	3·46	190	3·691	0·042	2·12	4·95

TABLE 4
Summary fork length (FL) and weight (W) of juvenile, male and female carp from Lakes Crescent and Sorell, Tasmania

		FL (mm)				W (g)			
Age (y)*	*n*	Mean	± SE	Min	Max	Mean	± SE	Min	Max
Juveniles									
1	2	296.0	26.0	270	322	669.0	111.0	558	780
2	29	317.6	6.2	228	375	823.9	40.8	316	1316
3	3	305.7	22.2	283	350	722.3	159.0	552	1040
Males									
1	1	315				874			
2	39	341.9	4.3	273	400	1036.0	39.4	458	1520
3	41	335.9	4.5	282	420	988.5	40.8	546	1778
4	4	367.0	23.4	302	407	1309.3	265.3	594	1765
5	2	435.5	19.5	416	455	1659.0	345.0	1314	2004
Females									
2	20	341.5	4.7	300	370	1046.0	54.8	600	1485
3	29	362.1	6.8	300	441	1238.9	77.7	681	2200
4	4	395.3	22.6	348	455	1733.5	351.1	1012	2662
5	1	417				1615			
6	1	528				4275			

* Estimated ages are based on annulus counts from whole and sectioned otoliths, in that order.

TABLE 5
Length-weight relationships for carp in Lakes Crescent and Sorell, Tasmania

Parameters*	All fish	Males + Females	Males	Females
n	332	255	168	87
a	3·5E-08	3·9E-08	1·1E-07	2·1E-08
b	2·943	2·927	2·753	3·028
r^2	0·900	0·987	0·989	0·986
RSS†		4·694	2·179	2·411
DF		253	166	85
F		2·840 (P = 0·060)		
Model‡	$W = 3{\cdot}5E\text{-}08FL^{2{\cdot}943}$	$W = 3{\cdot}9E\text{-}08FL^{2{\cdot}927}$	$W = 1{\cdot}1E\text{-}07FL^{2{\cdot}753}$	$W = 2{\cdot}1E\text{-}08FL^{3{\cdot}028}$

* Values for the parameters and tests of significance between sexes are shown (asymptotic standard errors were not available).
† The residual sum of squares (RSS) and the value and probability for the F-ratio test are indicated for comparisons between sexes. Since no significant differences were detected (α = 0·05) the pooled model is specified.
‡ Logarithms are to base 10; E, exponential notation; FL, fork length (mm); W, weight (kg).

Discussion

Formal validation of age assessments (*sensu* Beamish & McFarlane 1983) by MIA was limited to otoliths for three-year-old fish. Even so, the patterns of otolith development in two-year-old individuals (except in the January sample), and the relative distance of annuli from the nucleus in otoliths from all annulus groups in the stock, point to deposition of annual bands over 1–5 years.

The apparent lack of a new annulus in two-year-old fish at the beginning of the growing season (January–February) was perplexing: the mean MIR and the edges of otoliths with two annuli were typical of fish about to form a new annulus, and inconsistent with the low marginal increments and narrow opaque edges expected from annual deposition of bands. This probably was an artefact of the method used, given the presence of a single dominant year-class and the lack of younger age groups. The length-frequency analyses clearly showed that a single cohort dominated, consisting of age-group II individuals in 1995 and group III individuals in 1996 (notations here follow Jearld 1983). Age-group I carp, on the other hand, were not abundant in the samples (two individuals in February, one in March 1995). If an arbitrary 300 mm FL is used to separate I+ and II+ individuals (cf. pl. 1), age-group I was inconspicuous in 1995 and probably absent in 1996.

Validation of annulus counts by MIA was based on the most abundant 1993 year-class. Two specimens caught in

January 1996 accounted for the peak MIR value and the presence of "aberrant" edge types; these probably were fish yet to form the new annulus laid down by other members of the same age group. All carp with two annuli (except the two specimens captured in January) were caught in 1995, and specimens with three annuli sampled during January–February 1996 belonged to the same cohort. The few III+ specimens caught in September–November 1995 almost certainly were members of the 1992 cohort, which was represented by only two individuals in the January 1996 sample. For similar reasons, the low mean MIR for three-year old carp in January 1996 also is probably atypical, as it relates to the dominant 1993 cohort and does not include three-year-old fish about to form an annulus at the inception of their fourth year (this is the low-abundance January 1992 cohort).

The data presented here complement studies on carp in the River Murray (Vilizzi & Walker 1998, Vilizzi *et al.* 1998) and illustrate the tolerance of age estimates to changes in the timing of reproduction. In early 1995, the period with water temperatures above the spawning threshold lasted for three weeks. However, the 1996 summer was atypical, as a rise in water temperatures above the threshold would have been expected in mid-November. This has important consequences for the estimation of a birth-date. In the present study, 1 January was chosen, based on mean water temperatures and annulus formation in otoliths; however, a more precise estimate would be obtained by future monitoring of year-to-year variation in mean temperatures in the lakes and of carp reproduction. Further, an advantage with the proposed age adjustment methodology is that difficulties in interpreting results for small sample sizes and/or pronounced annual variation in recruitment are buffered, so that atypical individuals are assigned to the correct annulus group. The versatility of the method, a mathematical implementation to graphical representations of the edge interpretation problem (Francis *et al.* 1992), becomes evident if the following is postulated. In the unlikely case of a fish stock where all age classes form an annulus at the same time (birth-date), hence regardless of their age, no adjustment would be necessary, and the use of the annulus count corrections would simply have a null effect. Since variation in time of annulus formation is likely to be present in most fish stocks, adjustments are made whenever required.

The smaller widths of successive annuli in Lakes Crescent and Sorell carp may reflect more severe local climatic conditions compared to those in the River Murray, and may explain the lower readability of sectioned compared to whole otoliths. In the otoliths of Lakes Crescent and Sorell carp, translucent zones (under transmitted light) appeared as dark, thin areas intercalated with wider opaque zones, and the alternations were not clear after sectioning. The narrow bands of Lakes Crescent and Sorell carp may reflect a shorter slow-growth period than in the River Murray, where temperatures exceed 15°C for most of the year (Jones 1974).

ACKNOWLEDGEMENTS

We are grateful to Andrew Sanger and John Diggle, Inland Fisheries Commission, Hobart, for providing the sample of carp upon which this analysis is based and for comments on a draft manuscript. We are also indebted to David McGlennon and Bruce Jackson, South Australian Research and Development Institute, Adelaide, who provided access to equipment for sectioning otoliths.

REFERENCES

ANDERSON, J.R., MORISON, A.K. & RAY, D., 1992a: Age and growth of Murray cod, *Maccullochella peeli* (Perciformes: Percichthyidae), in the Lower Murray-Darling Basin, using thin-sectioned otoliths. *Aust. J. Mar. Freshw. Res.* 43: 983–1013.

ANDERSON, J.R., MORISON, A.K. & RAY, D., 1992b: Validation of the use of thin-sectioned otoliths for determining the age and growth of golden perch, *Macquaria ambigua* (Perciformes: Percichthyidae), in the Lower Murray-Darling Basin, Australia. *Aust. J. Mar. Freshw. Res.* 43: 1103–1128.

AUGUSTINE, O. & KENCHINGTON, T.J., 1987: A low-cost saw for sectioning otoliths. *J. Cons., Cons. Int. l'Explor. Mer* 43: 296–298.

BAGENAL, T.B. & TESCH, F.W., 1978: Age and growth. *In* Bagenal, T.B. (Ed.): *METHODS FOR ASSESSMENT OF FISH PRODUCTION IN FRESH WATERS.* Blackwell, Oxford: 101–136.

BACKE-HANSEN, P., 1982: Age determination, growth and maturity of the bleak *Alburnus alburnus* (L.) (Cyprinidae) in Lake Øyeren, SE Norway. *Fauna Norv. Ser. A* 3: 31–36.

BEAMISH, R.J. & MCFARLANE, G.A., 1983: The forgotten requirement for age validation in fisheries biology. *Trans. Am. Fish. Soc.* 112: 735–743.

BISHAI, H.M. & LABIB, W.D., 1978: Age and growth of mirror carp (*Cyprinus carpio* L.) at Serow Fish Farm. *Bull. Inst. Oceanogr. Fish.* 8: 397–418.

ENGLISH, T.S., 1952: Growth studies of the carp, *Cyprinus carpio* Linnaeus, in Clear Lake, Iowa. *Iowa State Coll. J. Sci.* 24: 527–540.

FRANCIS, R.I.C.C., PAUL, L.J. & MULLIGAN, K.P., 1992: Ageing of adult snapper (*Pagrus auratus*) from otolith annual ring counts: validation by tagging and oxytetracycline injection. *Aust. J. Mar. Freshw. Res.* 43: 1069–1089.

FULTON, W., 1990: Tasmanian freshwater fisheries. *FAUNA OF TASMANIA HANDBOOK 7.* University of Tasmania & Inland Fisheries Commission, Tasmania.

GUHA, D. & MUKHERJEE, D., 1991: Seasonal changes in the gonadal activity of common carp, *Cyprinus carpio* Linn. *Indian J. Fish.* 38: 218–23.

HAAS, R.E. & RECKSIEK, C.W., 1995: Age verification of winter flounder in Narragansett Bay. *Trans. Am. Fish. Soc.* 124: 103–111.

JEARLD, A. JR, 1983: Age determination. *In* Johnson, D.L. & Lampton, S.S. (Eds): *FISHERIES TECHNIQUES.* American Fisheries Society, Bethesda, Maryland: 301–324.

JONES, W., 1974: Age determination and growth studies of four species of fish from the River Murray. Unpubl. BSc Hons thesis, Dept Zool., Univ. Adelaide: 113 pp.

MANN, R.H.K., 1991: Growth and production. *In* Winfield, I.J. & Nelson, J.S. (Eds): *CYPRINID FISHES: SYSTEMATICS, BIOLOGY AND EXPLOITATION.* Chapman & Hall, London: 456–482.

MILLS, C.A., 1988: The effect of extreme northerly climatic conditions on the life history of the minnow, *Phoxinus phoxinus* (L.). *J. Fish Biol.* 33: 545–561.

MINA, M.V., 1989: Use of otoliths for age determination of cyprinid fishes. *J. Ichthyol.* 29 (7): 142–149.

O'MAOILEIDIGH, N. & BRACKEN, J.J., 1989: Biology of the tench, *Tinca tinca* (L.), in an Irish lake. *Aquacult. Fish. Manage.* 20: 199–209.

PANNELLA, G., 1980: Growth patterns in fish sagittae. *In* Rhoads, D.C. & Lutz, R.A. (Eds): *SKELETAL GROWTH OF AQUATIC ORGANISMS*. Plenum Press, New York: 519–560.

REHDER, D.D., 1959: Some aspects of the life history of the carp, *Cyprinus carpio*, in the Des Moines River, Boone County, Iowa. *Iowa State J. Sci.* 34: 11–26.

ROBERTS, J. & TILZEY, R. (Eds) (1997): *CONTROLLING CARP: EXPLORING THE OPTIONS FOR AUSTRALIA*. CSIRO Land and Water, Canberra: 132 pp.

SARIG, S., 1966: Synopsis of biological data on common carp (*Cyprinus carpio* L. 1758) (Near-East and Europe). *FAO Fisheries Synopsis* 31: 39 pp.

SPJOTVOLL, E. & STOLINE, M.R., 1973: An extension of the T-method of multiple comparison to include the cases with unequal sample sizes. *J. Am. Stat. Assoc.* 68: 976–978.

VILIZZI, L. & WALKER, K.F., 1995: Otoliths as potential indicators of age in common carp, *Cyprinus carpio* L. (Cyprinidae: Teleostei). *Trans. R. Soc. S. Aust.* 119: 97–98.

VILIZZI, L. & WALKER, K.F., 1998: Age and growth of carp, *Cyprinus carpio* L. (Cyprinidae), in the River Murray, Australia: validation, consistency of age interpretation and growth models. *Environ. Biol. Fishes* (in press).

VILIZZI, L., WALKER, K.F., JAIN, T., MCGLENNON, D. & TSYMBAL, V., 1998: Interpretability and precision of annulus counts for calcified structures in carp *Cyprinus carpio* L. *Arch. für Hydrobiol.* (in press).

WICHERS, W.F., 1976: Age and growth of carp (*Cyprinus carpio*) from Pathfinder Reservoir, Wyoming, 1974 and 1975. NOAA (National Marine Fisheries Service) Washington, D.C.: 69 pp.

(accepted 5 May 1998)

WHY DO TALL HERBS RARELY DOMINATE TASMANIAN ALPINE VEGETATION? EVIDENCE FROM ISLANDS IN THE OUSE RIVER SYSTEM

by K. L. Bridle and J. B. Kirkpatrick

(with five tables, one text-figure and two plates)

BRIDLE, K.L. & KIRKPATRICK, J.B., 1998 (31:xii): Why do tall herbs rarely dominate Tasmanian alpine vegetation? Evidence from islands in the Ouse River system. *Pap. Proc. R. Soc. Tasm.* 132: 9–14. ISSN 0080–4703. School of Geography and Environmental Studies, University of Tasmania, GPO Box 252-78, Hobart, Tasmania, Australia 7001

Tall alpine herbfield is largely absent from the Tasmanian alpine zone. This absence has been attributed to marsupial grazing. Small islands in the upper Ouse River valley are partly dominated by *Craspedia paludicola*, a showy tall alpine herb. The herbs dominate on the upstream ends of the islands. The surrounding vegetation on the banks is mainly grassland. The tall herbs are a very minor element of the shore vegetation, occurring on the undercut banks. Grassy islands close to the river banks are grazed and few tall herbs are found there. *Craspedia paludicola* also occurs in small numbers in damp areas on grassy heaths at other grazed locations, largely within bushes with pungent leaves. The distribution of *Craspedia paludicola* suggests that it is highly palatable and can thus only survive in larger numbers away from the influence of vertebrate grazers (rabbits and marsupials). It appears that this species requires both disturbance and a lack of grazing to dominate an area.

Key Words: tall alpine herbs, islands, grazing, Central Plateau, Tasmania, alpine vegetation.

INTRODUCTION

Tall alpine herbfield (sensu Costin *et al.* 1979) is one of the more widespread vegetation types in the Australian Alps. While many species that are found in mainland tall alpine herbfields occur in Tasmania, the community is largely absent from the Tasmanian alpine zone.

One of the main ecological differences between alpine areas in mainland Australia and those in Tasmania is the lack of grazing pressure from native herbivores on the mainland. The absence of marsupial herbivores on the mainland can be accounted for by the more continental climate of the Australian Alps, resulting in extended periods of snowlie (Carr & Turner 1959a, McVean 1969). As Tasmania has a maritime climate, persistent snowlie is restricted to the highest lee slopes, allowing vertebrate herbivores to survive and feed in the relatively unprotected vegetation of the alpine zone throughout the year (Kirkpatrick 1989).

The impacts of domestic stock and rabbit grazing on tall alpine herbs has been well documented for the Australian Alps (Carr & Turner 1959b, Wimbush & Costin 1979a,b,c, Leigh & Holgate 1979, Leigh *et al.* 1987, Williams & Ashton 1987, Wahren *et al.* 1994). However, very little information is available on the effects of native vertebrate herbivores on alpine vegetation. Leigh & Holgate (1979) found that plant survival and reproductive capacity were reduced by native vertebrate and rabbit grazing in the shrubby understorey of dry sclerophyll woodlands. Palatable forbs were considered to be the main food source of mammalian herbivores in subalpine environments (Leigh *et al.* 1991). However, the effects of native marsupial grazing have been found to be insignificant when compared to the effects of rabbits (Leigh *et al.* 1987).

In Tasmania, native herbivores (wallabies and wombats) affect the cover and heights of some shrubs and species of herbs in subalpine grassy woodlands (Gibson & Kirkpatrick 1989). Grazing by native herbivores and rabbits is considered to be the main mechanism for restricting the spread of exotic species across the Central Plateau (Kirkpatrick 1989, Whinam *et al.* 1994, Corbett 1996). In alpine *Sphagnum* bogs, epacridaceous shrubs are subject to heavy wallaby grazing (Whinam 1990). This study also indicated that grazing pressure was greater on individual palatable species in environments with relatively few palatable plants.

Rabbit numbers widely fluctuate on the Central Plateau and are heavily reduced during times of prolonged snowlie (Cullen 1995). Historical records detail the fluctuating numbers of kangaroo around the Great Lake area during the mid 1800s, where "... vast numbers of kangaroos perished through the cold" ... and during the summer of 1845 "... one man alone killed 1100 [kangaroos] in the vicinity of Lake Arthur...' (Breton 1846: 130).

Kirkpatrick (1989) postulated that the lack of tall alpine herbfield in Tasmania was due to the palatability of the herbs and the year round presence of introduced and native herbivores. He noted that tall alpine herbs were visibly abundant in places which were isolated from grazing, such as fenced plots and islands in fast-flowing, deep streams (e.g. the Ouse River system).

This paper documents the environments, vegetation and grazing incidence on several of the islands in the Ouse River system and the adjacent banks. Our working hypothesis was that the exclusion of grazing by a fast-flowing deep stream would result in a greater degree of tall herb cover than in adjacent, environmentally similar areas.

METHODS

In January 1997, five islands in the upper Ouse River valley, on the eastern Central Plateau, Tasmania, were surveyed (fig. 1). These islands were the first five seen on a traverse of the region. The closest adjacent area of the same size on the banks of the rivers was also surveyed.

The following data were recorded:

- dimensions of the island;
- minimum distance from the island to the shore;
- presence and cover of vascular plant taxa using the following

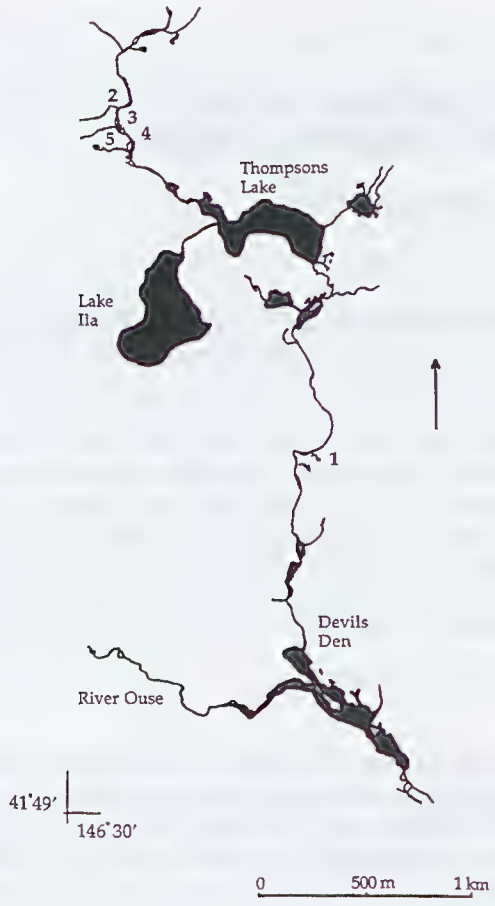


FIG. 1 — The upper Ouse River system showing the location of the island and shore sites (1–5) surveyed.

scale — 1 = <1%, 2 = 1–5%, 3 = 5–25%, 4 = 25–50%, 5 = 50–75%, 6 = 75–100%;

• presence, identity and number of scats present.

Plant nomenclature follows Buchanan (1995) except for *Chionogentias* spp. (L.G. Adams 1995).

Three bulked samples of surface soil (< 5 cm deep) were taken from each island and adjacent shore. These were analysed for copper, iron, manganese, zinc, ammonium N, nitrate N, total nitrogen, total phosphorus, total calcium, extractable phosphorus, extractable potassium, organic carbon, conductivity and pH, using the following methods — DTPA for Cu, Fe, Mn, Zn; KCl extraction for NH_4/N, NO_3/N; semimicro Kjeldahl, steam distillation for total N; ICP analysis for total P & Ca; bicarbonate-extractable P; bicarbonate-extractable K; organic C (Walkley & Black); pH($CaCl_2$) 1:5 soil/0.01M calcium chloride extract; conductivity 1:5 soil/water extract (Rayment & Higginson 1992).

Plant species were grouped according to lifeform: shrub, grass, herb (dicotyledons), graminoids (herbaceous monocotyledons other than members of the Poaceae). Herbs were further divided into three groups on the basis of stature; tall alpine herbs (*sensu* Costin *et al.* 1979), medium stature herbs (between 5 and 10 cm tall) and small herbs (less than 5 cm tall). All "small herb" *Ranunculus* species were grouped under the genus.

The numbers of Bennett's wallaby (*Macropus rufogriseus*) and wombat (*Vombatus ursinus*) scats and plant species richness were calculated for each pair of island/shore plots. The Mann-Whitney U test was used to determine whether there were any significant differences in soil characteristics or numbers of scats between the islands and the shores, while the Wilcoxon signed-rank test was used to test for significant differences in species richness between the paired plots. The Fisher's Exact Probability test was used to determine the significance of differences between the distribution of individual taxa on islands and shores.

The midpoints of the cover classes were used to estimate the total cover of lifeforms for each of the island/shore plots. The Fisher's Exact Probability test was used to determine the significance of different lifeform groups on islands and shores.

RESULTS

The islands varied in size from 2.25 to 24 m^2 and were from 1.5 to 12 m away from the shores (table 1).

The number of scats recorded for the islands and the shore was significantly different ($z = -2.643$, $p = 0.0082$). Not surprisingly, the only scats recorded on the islands were wallaby scats, whilst both wallaby and wombat scats were recorded on the shore. Scats were only found on islands four and five which lay less than 2 m away from the river bank (tables 1, 2).

There were no significant differences between the soils of the island and the shore sites (table 3).

In all, 40 plant species were identified on the islands and adjacent shores. Most of the species recorded were herbs (23/40) followed by graminoids and shrubs (table 4).

Only one species, *Plantago daltonii*, occurred in all ten plots, while 13 species occurred in one plot only (table 4). Species richness was consistently higher in the shore plots than on the islands ($z = -2.812$, $p = 0.0049$) (table 4).

The grass *Hierochloe redolens*, the graminoid *Carpha alpina* and the tall alpine herb *Craspedia paludicola* were the only species to have significantly different frequency distributions on the islands and the shores ($p = 0.004$ for all three species).

There was no significant difference in the presence or cover of shrubs, grasses, graminoids or small herbs between the islands and the shore sites. Medium stature herbs (h) and tall herbs (tah) were significantly more abundant on the islands ($p = 0.024$, $p = 0.004$ respectively).

Seven species occurred on the islands only, while 11 species were recorded for the shore sites only (table 5). Of these, small herbs made up the greater proportion of plants recorded for the shore sites only. Tall herbs and grass species were faithful only to the islands.

DISCUSSION

Visually, the tall herb *Craspedia paludicola* identifies the main difference in species composition and stature between the island and the shore sites (pl. 1). This difference in the vegetation cannot be attributed to differences in soil fertility (table 3). These islands do differ from the shores in the number of scats per unit area with several having none (table 2). We were unable to measure flood disturbance impacts but deduce that these would be greatest on the upstream ends of islands and least on the downstream ends. There seems little doubt that flood activity favours the establishment of tall herbs as these were concentrated on the

TABLE 1
Physical characteristics of the five paired sites

Island	Dimensions (m)	Distance to banks West	East
1	4 x 6	2 m	4 m
2	2 x 2	3 m	6 m
3	1.5 x 1.5	6 m	6 m
4	3 x 2	8 m	1.5 m
5	4 x 2	12 m	2 m

TABLE 2
Number of scats/m²

Site	Number of scats Islands	Shores	Identity of scats Islands	Shores
1	0	0.9		Wallaby
2	0	9.5		Wallaby/wombat
3	0	14.2		Wallaby
4	2.3	5.8	Wallaby	Wallaby
5	1	6.4	Wallaby	Wallaby/wombat

TABLE 3
Soils analyses for the island and the shore sites

	Cu ppm	Fe ppm	Mn ppm	Zn ppm	NH_4 ppm	NO_3 ppm	N %	P ppm	Ca ppm	ExtP ppm	ExtK ppm	C %	Cond. dS/M	pH $CaCl_2$
Shore														
1	0	0	0	0	39	0.05	0.81	643	2945	3	265	17.8	0.08	5.6
2	2.34	241.2	753	6.4	37	0.05	0.87	771	1485	1	530	14.8	0.07	6.1
3	3	293	432	12	149	0.05	0.88	794	954	1	340	15.5	0.06	4.9
4	4.95	495	513	13.5	22	0.05	0.83	865	537	1	260	13.5	0.05	4.7
5	3.15	614	507	15.3	37	0.05	0.8	790	801	2	410	15.4	0.06	4.9
mean	2.69	328.6	441	9.44	56.8	0.05	0.84	772.6	1344.4	1.6	361	15.4	0.06	5.2
sd	1.79	237.7	274.5	6.23	52		0.04	80.8	959.3	0.9	112.7	1.56	0.01	0.6
Island														
1	0	0	0	0	116	0.05	0.97	690	3355	2	350	16.5	0.08	5.3
2	2.88	386.4	285.6	5.57	23	0.05	0.94	710	1154	2	430	14.6	0.09	6
3	3.6	348	597	11.7	31	0.05	0.86	835	1548	2	590	12.9	0.11	5.1
4	3.12	383.4	678.6	12.7	42	0.05	0.78	840	737	3	275	14.9	0.06	4.8
5	2.76	279	282	7.83	35	0.05	0.74	766	824	2	190	11.5	0.07	5.8
mean	2.47	279.4	368.6	7.56	49.4	0.05	0.86	768.2	1523.6	2.2	367	14.1	0.08	5.4
sd	1.42	162	273.1	5.12	37.9		0.1	69.2	1072.3	0.5	153.1	1.93	0.02	0.5

PLATE 1
An ungrazed island in the upper Ouse River system, dominated by Craspedia paludicola *on the upstream end. Vegetation on the opposite shore shows* C. paludicola *on the undercut banks only.*

upstream ends of islands and on the vertical banks of both the islands and the shore. However, on the shores the tall herbs are only found where the steepness of banks prevented grazing while on the islands they occurred throughout.

The dominant grass species *Hierochloe redolens,* which occurred on the downstream ends of the islands, was rare on the shore. Small herbs that were absent on the highly grazed shore were rare in the taller vegetation of the islands. Many of the species more common on the islands are reported to be palatable and/or not grazing resistant. The tall herb species on the islands are considered to be very palatable and relatively intolerant to grazing (Carr & Turner 1959a,b, Wimbush & Costin 1979a,b, Leigh *et al.* 1987, Wahren *et al.* 1994). The shrub *Bellendena montana* is also palatable to native herbivores. Of those species faithful to the shore (table 5), the following are grazing resistant; *Cotula alpina* (Gibson & Kirkpatrick 1989, Leigh *et al.* 1987), *Hydrocotyle sibthorpioides* (Gibson & Kirkpatrick 1989), *Hypericum japonicum* and *Viola betonicifolia* (Gibson & Kirkpatrick 1989, Leigh *et al.* 1987). *Astelia alpina* is palatable to native vertebrates when choice of food is limited (Whinam 1990). *Asperula gunnii* (Gibson & Kirkpatrick 1989, Leigh *et al.* 1987), *Epacris gunnii* (Gibson & Kirkpatrick 1989, Whinam 1990) and *Epacris serpyllifolia*

TABLE 4
Cover of species and lifeforms in the island/shore paired plots

	life	island 1	shore 1	island 2	shore 2	island 3	shore 3	island 4	shore 4	island 5	shore 5
Astelia alpina	gm				0.5		0.5				
Carex gaudichaudiana	gm			2.5	37.5	15	2.5	62.5	2.5	0.5	2.5
Carpha alpina	gm		0.5		0.5		37.5		15	2.5	15
Empodisma minus	gm	37.5	62.5								15
Oreobolus distichus	gm		0.5								
Restio australis	gm	2.5	15								
Deschampsia caespitosa	gr					2.5					
Hierochloe redolens	gr	2.5	0.5	37.5	0.5	0.5		0.5		62.5	2.5
Poa costiniana	gr	37.5	37.5	2.5	15	0.5	2.5		2.5	37.5	37.5
Acaena montana	hs		0.5								
A. novae-zelandiae	hs	0.5	0.5								
Asperula gunnii	hs		0.5				2.5				0.5
Cotula alpina	hs				0.5						
Dichosciadeum ranunulaceum	hs	0.5	0.5		0.5						
Diplaspis hydrocotyle	hs	0.5	0.5		0.5	0.5	0.5	0.5	0.5		
Hydrocotyle sibthorpioides	hs		0.5								2.5
Hypericum japonicum	hs		0.5				0.5				
Oreomyrrhis ciliata	hs			2.5	0.5		0.5	2.5	0.5	2.5	2.5
Ourisia integrifolia	hs		0.5	0.5	0.5	0.5	0.5	0.5	2.5		
Ranunculus sp.	hs	0.5	0.5	38.5	3	65	62.5	15.5	63.5	3	3
Viola betonicifolia	hs										0.5
V. cunninghamii	hs			0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5
Epilobium sp.	h		0.5								
Geranium potentilloides	h	2.5	0.5								
Plantago daltonii	h	0.5	0.5	15	0.5	15	0.5	2.5	2.5	2.5	0.5
Ranunculus lappaceus	h					0.5	0.5				
Chinogentias sp.	tah			0.5							
Craspedia coolaminica	tah	0.5									
C. paludicola	tah	2.5	0.5	62.5	0.5	37.5		0.5		2.5	0.5
Baeckea gunniana	sh	2.5	2.5								
Bellendena montana	sh	0.5									
Coprosma sp.	sh	0.5									
Epacris gunnii	sh		0.5								
E. serpyllifolia	sh		0.5								
Olearia obcordata	sh	2.5	0.5								
Orites acicularis	sh	15	15								
Richea acerosa	sh	2.5	15								
total graminoids	gm	40	78.5	2.5	38.5	15	40.5	62.5	17.5	3	32.5
total grasses	gr	40	38	40	15.5	3.5	2.5	0.5	2.5	100	40
total small herbs	hs	2	4.5	42	6	66.5	67.5	21.5	67.5	6	9.5
total medium herbs	h	3	1.5	15	0.5	15.5	1	2.5	2.5	2.5	0.5
total tall herbs	tah	3	0.5	63	0.5	37.5	0	0.5	0	2.5	0.5
total all herbs	h	8	6.5	120	7	119.5	68.5	24.5	70	11	10.5
total shrubs	sh	23.5	34	0	0	0	0	0	0	0	0
species richness/m^2		18/24	25/24	12/4	15/4	12/2.3	13/2.3	10/6	11/6	10/8	14/8

Life = lifeform group; gm = graminoid, gr = grass, hs = small herbs, h = medium stature herbs, tah = tall herbs, sh = shrubs.
Species names and lifeform groups in bold type have significantly different frequency distributions on the islands and the shores.

TABLE 5
Lifeforms of species occurring only on either the islands or the adjacent shores

Species	Island	Shore
Astelia alpina		graminoid
Oreobolus distichus		graminoid
Deschampsia caespitosa	grass	
Acaena montana		small herb
Asperula gunnii		small herb
Cotula alpina		small herb
Epilobium sp.		small herb
Hydrocotyle sibthorpioides		small herb
Hypericum japonicum		small herb
Viola betonicifolia		small herb
Ranunculus glabrifolius	small herb	
R. rivularis	small herb	
Chinogentias sp.	tall herb	
Craspedia coolaminica	tall herb	
Bellendena montana	shrub	
Coprosma sp.	shrub (mat)	
Epacris gunnii		shrub
E. serpyllifolia		shrub

PLATE 2
A lightly grazed island in the upper Ouse River system, showing Craspedia paludicola *only on the undercut banks of the island and the shore.*

(Whinam 1990) are palatable species, though they can tolerate some grazing.

Grazing can affect the overall stature of communities and individual taxa. The difference in stature of herbs that we found between the islands and shores is likely to be related to grazing pressure. Wimbush & Costin (1979a, c) found densities of minor herbs to be less in grazing exclosures over time while tall herbs increased. The dominance of small herbs on the shore sites suggests that grazing is important in creating and maintaining habitat requirements (and higher species richness) where small herbs are not outcompeted by taller species (Wimbush & Costin 1979a). Small herbs existing on the islands had suitable habitat provided for them by disturbance from the river itself, such as bank erosion and occasional flood events. Where grazing is present on the islands, the cover of *Craspedia paludicola* is less than where grazing is absent (table 4, see data for islands 4 and 5).

Similar reports on community composition on ungrazed islands have been noted elsewhere on the Central Plateau. Colonel Legge, on visiting the now drowned Pine Island in Great Lake, recorded a plant community dominated by "... the tall Alpine Holy grass *Hierochloe redolens*, the *Craspedia richei* whose tall stalk and downy, button-shaped flower towered above the dwarf *Poa* grass ..." (Legge 1902: 141). Other tall herbs such as "*Brachycome* sp.", "*Helichrysum bracteatum*" and "*Celmisia longifolia*" were also noted. Legge did not see any sign of vertebrate herbivores whilst he was on the island, and his companions only reported sightings of whip-snakes, echidnas and pipits.

Islands in the Ouse River system were grazed if they were in close proximity to the shore or to other islands. Where there were a series of islands linked together, scats were found on them all. While *Hierochloe redolens* was present on these grazed islands, *Craspedia paludicola* was noticeably absent or present only on the steep undercut banks (pl. 2). These islands were generally larger or more protected than the islands with tall herbs, due to their proximity to other islands, and they appear to be physically more stable. The dominance of *C. paludicola* on the upstream ends of the surveyed islands and along the undercut banks suggests that it is able to withstand physical disturbance and may indeed require it, in order to gain dominance in a strongly competitive environment.

The dominance of tall alpine herbs in herb-rich grasslands on the mainland may be partly a result of some disturbance event(s) (Carr & Turner 1959a, McVean 1969, Costin *et al.* 1979). Tall herbs such as *Craspedia* spp. are capable of colonising bare ground (Wahren *et al.* 1994), and they are also opportunistic when gaps appear in the vegetation, such as during the senescence of *Poa* tussocks or shrubs (Carr & Turner 1959b, McVean 1969, Costin *et al.* 1979). Where exogenous disturbances (such as domestic stock grazing) have been removed, the most commonly recorded effect in the plant community is an increase in species richness and cover of tall alpine herbs (Carr & Turner 1959b, Wimbush & Costin 1979a,b,c, Wahren *et al.* 1994). Whether tall alpine herbfields persist in the long term appears to rely on occasional extreme climatic events, such as drought or extended snowlie, or exogenous disturbance, such as fire. In Tasmania, climatic events may not be so extreme, but endogenous disturbance in the form of grazing exists. While disturbance itself may be a necessary requirement for tall alpine herbs to dominate in grasslands, they need to be able to reproduce to do so!

Given the above reasoning, we accept our working hypothesis by concluding that an absence of marsupial grazing is necessary for tall herbs to have the opportunity to obtain dominance in Tasmanian alpine vegetation on fertile soils. However, we also conclude that this has to be combined with physical disturbance to ensure tall herb dominance.

ACKNOWLEDGEMENTS

We would like to thank Abe Francis for assistance in the field. The Parks and Wildlife Service, Tasmania, issued us with permits to carry out this research which was funded by the ARC.

REFERENCES

Adams, L.G., 1995: *Chionogentias* (Gentianaceae), a new generic name for the Australian "snow-gentians", and a revision of the Australian species. *Aust. Syst. Bot.* 8: 935–1011.

Breton, W.H., 1846: Excursion to the Western Range, Tasmania. *Tasm. J. Nat. Sci.* II: 121–141.

Buchanan, A.M. (Ed.), 1995: *A CENSUS OF THE VASCULAR PLANTS OF TASMANIA. Tasm. Herb. Occ. Publ.* 5. Tasmanian Herbarium, Hobart.

Carr, S.G.M. & Turner, J.S., 1959a: The ecology of the Bogong High Plains. I. The environmental factors and the grassland communities. *Aust. J. Bot.* 7: 12–33.

Carr, S.G.M. & Turner, J.S., 1959b: The ecology of the Bogong High Plains. II. Fencing experiments in grassland C. *Aust. J. Bot.* 7: 34–63.

Corbett, E.B., 1996: *VEGETATION OF THE CENTRAL PLATEAU TASMANIAN WILDERNESS WORLD HERITAGE AREA. Wildl. Rep.* 95/3. Parks & Wildlife Service, Tasmania, Hobart.

Costin, A.B., Gray, M., Totterdell, C.J. & Wimbush, D.J., 1979: *KOSCIUSKO ALPINE FLORA.* CSIRO/Collins, Sydney.

Cullen, P., 1995: *LAND DEGRADATION ON THE CENTRAL PLATEAU, TASMANIA: THE LEGACY OF 170 YEARS OF EXPLOITATION. Occ. Pap.* 34. Parks & Wildlife Service, Tasmania, Hobart.

Gibson, N. & Kirkpatrick, J.B., 1989: Effects of the cessation of grazing on the grasslands and grassy woodlands of the Central Plateau, Tasmania. *Aust. J. Bot.* 37: 55–63.

Kirkpatrick, J.B., 1989: The comparative ecology of mainland Australian and Tasmanian alpine vegetation. *In* Good, R. (Ed.): *THE SCIENTIFIC SIGNIFICANCE OF THE AUSTRALIAN ALPS.* Australian Alps National Parks Liaison Committee. CPN Publications: Ch. 8.

Legge, W.V., 1902: Contribution to the physiography of Tasmania. *Pap. Proc. R. Soc. Tasm.* 1902: 137–142.

Leigh, J.H. & Holgate, M.D., 1979: The responses of the understorey of forests and woodlands of the Southern Tablelands to grazing and burning. *Aust. J. Bot.* 4: 25–45.

Leigh, J.H., Wimbush, D.J., Wood, D.H., Holgate, M.D., Slee, A.V., Stanger, M.G. & Forrester, R.I., 1987: Effects of rabbit grazing and fire on a subalpine environment. I. Herbaceous and shrubby vegetation. *Aust. J. Bot.* 35: 433–464.

Leigh, J.H., Wood, D.H., Slee, A.V. & Holgate, M.D., 1991: The effects of burning and simulated grazing on productivity, forage quality, mortality and flowering of eight subalpine herbs in Kosciusko National Park. *Aust. J. Bot.* 39: 97–118.

McVean, D.N., 1969: Alpine vegetation of the central Snowy Mountains of New South Wales. *J. Ecol.* 57: 67–86.

Rayment, G.E. & Higginson, F.R., 1992: *AUSTRALIAN LABORATORY HANDBOOK OF SOIL AND WATER CHEMICAL METHODS.* Inkata Press, Melbourne.

Wahren, C-H.A., Papst, W.A. & Williams, R.J., 1994: Long term vegetation change in relation to cattle grazing in subalpine grassland and heathland on the Bogong High Plains: an analysis of vegetation records from 1945 to 1994. *Aust. J. Bot.* 42: 607–639.

Whinam, J., 1990: A study of the ecology of Tasmanian *Sphagnum* peatlands.. Unpubl. PhD Thesis, Univ. Tasm., Hobart.

Whinam, J., Cannell, E.J., Kirkpatrick, J.B. & Comfort, M., 1994: Studies on the potential impact of recreational horseriding on some alpine environments of the Central Plateau, Tasmania. *J. Environ. Man.* 40: 103–117.

Williams, R.J. & Ashton, D.H., 1987: The composition, structure and distribution of heathland and grassland communities in the subalpine tract of the Bogong High Plains, Victoria. *Aust. J. Ecol.* 12: 155–163.

Wimbush, D.J. & Costin, A.B., 1979a: Trends in vegetation at Kosciusko. I. Grazing trials in the subalpine zone, 1957–1971. *Aust. J. Bot.* 27: 741–787.

Wimbush, D.J. & Costin, A.B., 1979b: Trends in vegetation at Kosciusko. II. Subalpine range transects, 1959–1978. *Aust. J. Bot.* 27: 789–831.

Wimbush, D.J. & Costin, A.B., 1979c: Trends in vegetation at Kosciusko. III. Alpine range transects, 1959–1978. *Aust. J. Bot.* 27: 833–871.

(accepted 3 February 1998)

CHANGES IN SOUTHWESTERN TASMANIAN FIRE REGIMES SINCE THE EARLY 1800s

by Jon B. Marsden-Smedley

(with five tables and one text-figure)

MARSDEN-SMEDLEY, J.B., 1998 (31:xii): Changes in southwestern Tasmanian fire regimes since the early 1800s. *Pap.Proc. R. Soc. Tasm.* 132: 15–29. ISSN 0040–4703. School of Geography and Environmental Studies, University of Tasmania, GPO Box 252-78, Hobart, Tasmania, Australia 7001.

There have been major changes in the fire regime of southwestern Tasmania over the past 170 years. The fire regime has changed from an Aboriginal fire regime of frequent low-intensity fires in buttongrass moorland (mostly in spring and autumn) with only the occasional high-intensity forest fire, to the early European fire regime of frequent high-intensity fires in all vegetation types, to a regime of low to medium intensity buttongrass moorland fires and finally to the current regime of few fires. These changes in the fire regime resulted in major impacts to the region's fire-sensitive vegetation types during the early European period, while the current low fire frequency across much of southwestern Tasmania has resulted in a large proportion of the region's fire-adapted buttongrass moorland being classified as old-growth. These extensive areas of old-growth buttongrass moorland mean that the potential for another large-scale ecologically damaging wildfire is high and, to avoid this, it would be better to re-introduce a regime of low-intensity fires into the region.
Key Words: fire regimes, fire management, southwestern Tasmania, Aboriginal fire, history.

> After much fatigue in getting through, we suddenly, on reaching the top of the hill, opened into ground recently burnt, with a most beautiful valley extending SW, beneath us. The whole of this ground had been burnt, apparently immediately before the late snow, and I conclude, by the natives. The valley had the appearance, at a distance, of undergoing all the processes of agriculture, – some parts looking like freshly ploughed fields; and again, other parts possessing the most beautiful verdure from the sprouting of the young grasses and rushes.
>
> (William Sharland in 1832 on the Loddon Plains, southwestern Tasmania.)

INTRODUCTION

Recurrent fire is a characteristic part of many wildland environments. This is particularly the case in southwestern and western Tasmania, where many thousands of years of human land use have contributed to the genesis of a rich mosaic of fire-tolerant and fire-sensitive vegetation types. These communities are typically juxtaposed and range from the highly fire-tolerant and fire-dependent buttongrass moorlands, through the increasingly fire-sensitive but still fire-dependent wet scrub and wet eucalypt forest to the fire-sensitive rainforest and coniferous heath communities.

Worldwide, there is an increasing need for active fire management in fire-adapted vegetation, due to the interdependence between fire and vegetation, cessation of burning by traditional societies, enhanced awareness of ecological values, increasing human pressures (of both economy and population) and wildland fragmentation.

The vegetation patterns of southwestern Tasmania are far from unaffected by humans. In this region, humans are responsible for the majority of fires (Marsden-Smedley 1997), and variation in the fire regime is one of the dominant factors determining the balance between the major vegetation assemblages (Jackson 1968). Jackson postulated that, in the absence of fire, rainforests and rainforest-scrub would dominate the vegetation, with the only significant exceptions probably being sites with highly waterlogged soils and/or extreme levels of climatic exposure. Fire acts to modify these vegetation distributions, greatly increasing the area of the fire-adapted moorland, wet scrub and wet eucalypt forest. There is considerable anecdotal evidence for major changes in the fire regime of southwestern Tasmania since the removal of the Tasmanian Aborigines in the 1830s. Historical and contemporary reports suggest that there were frequent fires before about the 1940s, with major fires occurring in the 1890s and 1930s. There are also very extensive areas of fire-sensitive vegetation which appear to have been degraded by fire (Brown 1988, Peterson 1990, Robertson & Duncan 1991).

This paper examines some of these issues. If changes in the fire regime did occur, this would have major implications for fire management and ecological processes in southwestern Tasmania. This would be due, at least in part, to the interactions between the time since fire and fire behaviour. For example, should we be performing active fire management in southwestern Tasmania or maintaining the current policy of benign neglect (Brown 1996)? Therefore, in order to assess the options for management in southwestern Tasmania objectively, information is required as to the fire history of the region.

METHODS OF ASSESSING FIRE REGIMES

Information on the fire regime of southwestern Tasmania was collated from published papers, fire history records, historical records, aerial photographs and site records. The area assessed consisted of the Southwest and Franklin-Gordon National Parks and those parts of the Southwest Conservation Area that are on Cape Sorell or adjacent to the King River and Macquarie Harbour. This region has a total area of about 1 227 200 ha.

Attempts were also made to characterise the fire regime likely to be utilised by the Tasmanian Aborigines. This regime was determined using published papers, fire behaviour theory and observations of ecological processes in southwestern Tasmania.

Published papers

Historical records of fires were assessed. In these records, up to about the 1930s, the prevailing attitude was that it was an advantage to burn-off the country when performing exploration and/or building access tracks (see pp.19–22). As a result, about two thirds of these records contain extensive references to the areas burnt and the type of fires used. In particular, the following were used: *Tasmanian House of Assembly Journal; Legislative Council Journal, The Mercury* [newspaper]; *Explorers of Western Tasmania* (Binks 1980); *Trampled Wilderness* (Gowlland & Gowlland 1976); *Tasmanian Mail*; Notes on forest classification and fire occurrence (Gilbert 1978); Fires in the Tasmanian bush (Gilbert 1979) and *History of Emergency Events 1* (State Emergency Service 1990). The unpublished records in the Archives Office of Tasmania were also extensively used. The historical records (i.e. records predating the 1930s) assessed for fire histories are listed in Marsden-Smedley (1997).

These records give a good indication of when and where fires occurred between about the 1850s and the 1930s but only contain limited information on fire size. These records also mainly document "official" exploration and track-cutting parties and so give only limited information on private parties. Therefore, the historical records need to be used with caution. For example, in some areas, there was considerable private exploration, particularly for Huon pine (*Lagarostrobos franklinii*), which may have been associated with extensive burning-off. This probably would have been most marked in the lower Gordon and Davey River regions (Perrin 1887, 1898). As a result, although it is not possible to determine the area burnt from the historical records, they probably do give a reasonable indication of when the major fires occurred.

Field Data and Aerial Photograph Interpretation

Site age (i.e. time since the last fire) information was collated from a total of 161 sites from published sources (in particular, Jarman *et al.* 1988a). Fire ages were then sampled from an additional 107 sites, to target areas where there were gaps in the stem aging. The sites assessed are shown in Marsden-Smedley (1997). The fire history maps held by the Fire Management Branch, Parks and Wildlife Service, Tasmania, were also used for checking the ages recorded from different sites.

Sites were aged in the field wherever possible by counting banksia (*Banksia marginata*) nodes (Bell 1983, Jarman *et al.* 1988a), with species annual rings being used where banksias were absent. Where possible, ring counts were made from tea-tree species, due to their reliable, easily counted rings. The tea-tree species used included shiny tea-tree (*Leptospermum nitidum*), manuka (*L. scoparium*), *L. glaucescens* and woolly tea-tree *L. lanigerum*). Where tea-tree species were not present, white waratah (*Agastachys odorata*) and/or eucalypts (*Eucalyptus coccifera* and *E. nitida*) were used, but these species frequently displayed poor ring structure, resulting in problem in determining site age. Paper-bark species (*Melaleuca* spp.) were not used, since their poor ring structure resulted in an excessive number of individuals being required. Ring counts were made using a dissecting microscope from the lower surface of cross-sections cut from just above the ground. These cross-sections had been dried and polished with up to 1200 grade sandpaper. A minimum of six individuals were counted at each site. Previous studies (i.e. Marsden-Smedley 1990, 1993a) and extensive cross-checking in this project have shown that site age is typically equal to the ring count mode when species are regenerating vegetatively, and equal to the ring count mode plus one when species are regenerating from seed.

In most parts of southwestern Tasmania, major problems occurred in mapping fires older than the 1930s. This was due to the very extensive area burnt in the 1930s, which removed much of the evidence of the older fires. As a result, the area burnt in the 1890s has only been estimated, and all other fires older than the 1930s have been recorded descriptively. From the 1930s on, fire boundaries and areas burnt have been identified from aerial photographs and/or fire history maps.

All available aerial photographs taken of the study area between 1946 and 1970 in the Department of Environment and Land Management Land Information Bureau were examined for fire boundaries (table 1). These aerial photographs were arranged in projects, typically containing five to 18 runs, each of about 30 to 40 photographs. In addition, aerial photographs of the Port Davey, Wedge and King William areas, taken in the mid to late 1970s, were examined to assess areas inadequately covered by the earlier photographs. In total, about 7000 aerial photographs were examined for fire boundaries.

TABLE 1
Aerial photographs examined for fire boundaries

Project	Run(s)	Date
King William	1 to 12	1946
Styx	1 to 14	1946
St Clair	6 to 12	1947
Adamsons	1 to 14	1948
Arthur	1 to 3	1948
Bathurst	1 to 10, all ties	1948
Huntley	1 to 5	1948
Maatsuyker	1 to 4	1948
Picton	1 to 16	1948
South Cape	1 to 7	1948
Lyell	1 to 14	1949
Pedder	1 to 8, all ties	1949
Pillinger	1 to 7	1949
Rocky Point	1 to 4, east tie	1949
King–Franklin	1 to 10	1953
King William	5 to 9	1953
Macquarie Harbour	1 to 7	1953
Gordon	1 to 6	1958
Tasmania southwest	1 to 15, all ties	1960
Port Davey, F367	1 to 9	1973
Wedge, F366	1 to 4	1973
King William, F585	1 to 4	1978

Aerial photographs and fire history maps were used together, in order to standardise the recording of fires on the older aerial photographs. This system also largely overcomes a problem with the fire history maps from the 1960s and, to a lesser extent, the early 1970s, when only the larger and/or higher intensity fires were mapped. In general, fire history maps were used for fires after 1975, whilst aerial photographs were used for fires before 1975. The ages estimated from aerial photographs were also checked against fire history records and other aerial photographs taken of the same location at different times. Where possible, the fires identified from aerial photographs were aged to the nearest year, using the data from the site records. For some fires, however, this was not possible, and the fires were allocated a decade. Marsden-Smedley (1997) contains a list of all recorded fires in southwestern Tasmania.

The area of different vegetation types burnt in different decades was assessed by comparing the fire history maps generated in this project (see fig. 1) with a vegetation map of the region. This vegetation map was based on a map produced by Kirkpatrick & Brown (1991) and showed areas of rainforest, eucalypt forest and non-forest. It also showed the original vegetation type in areas flooded for hydro-electric schemes.

In order to assess the amount of subalpine and alpine vegetation burnt, these communities were assumed to occur at altitudes greater than 100 m below the local treeline (J. B. Kirkpatrick, pers. comm.). The height at which the treeline occurred was assessed from the published literature (e.g. Kirkpatrick 1982, 1984a, b, Kirkpatrick & Brown 1987, Kirkpatrick *et al.* 1996, Bridle & Kirkpatrick 1997). This height, above which the subalpine and alpine vegetation was assumed to occur, varied from 600 m in the far southwestern corner of the region (e.g. Mt Rugby, Mt Counsel, South West Cape Range), 800 m in the central and eastern part of the region (e.g. Southern Ranges, Eastern and Western Arthur Ranges, Frankland Range) to 1000 m in the western and northern parts of the region (e.g. West Coast Range, Frenchmans Cap, Spires, King William Range).

Fire History Map Production

The information gained from the published papers, fire history records and aerial photographs was used to generate 1:100 000 scale fire history base maps for southwestern Tasmania. These base maps were used to produce a 1:250 000 fire history map of the whole region, which was then digitised. Fires were assigned to one of the following age classes: 1890s, 1930s, 1940s, 1950s, 1960s, 1970s, 1980s, 1990 to 1996. As has already been mentioned, it was not possible to map the area burnt between the 1890s and 1930s.

FIRE REGIMES IN SOUTHWESTERN TASMANIA SINCE THE 1830s

There is strong evidence for major changes in fire regime across southwestern Tasmania in the last 170 years. This period can be divided into four broad categories: pre-1830 (Aboriginal), 1830s to 1930s (early European), 1940 to about 1970 (middle European) and post 1970 (i.e. current).

Aboriginal Fire Regime

There has been some conjecture in literature regarding Aboriginal occupation of southwestern Tasmania during the late Pleistocene and Holocene. Some authors suggest the region has been, in fact, largely unoccupied since some time during the period 12–8 ka (e.g. Plomley 1966, Cosgrove *et al.* 1994), while other authors suggest at least seasonal occupation until historical times (e.g. Kiernan *et al.* 1983, Flanagan 1985, Jones 1993, Thomas 1993a). Whilst little, if anything, can be deduced from the work reported on in this paper regarding the social and/or cultural importance of fire for the Tasmanian Aborigines, much can be deduced as to whether Aborigines occupied the region and, if so, the type of fire regime utilised and its effects on the region's ecology.

At the time of European settlement, there were extensive buttongrass plains throughout southwestern Tasmania (Goodwin 1828, Little 1833, Frankland 1835, 1836, Burn 1842, Lewis & McPartlan 1859, Calder 1860a, b, c, Sharland 1861, also Plomley 1966, Gowlland & Gowlland 1976, Binks 1980). Ecologically, it is highly unlikely that such extensive plains would have persisted in the absence of human-mediated fires for more than about 250 to 1000 years (Jackson 1968, Jarman *et al.* 1988b, Marsden-Smedley 1990). In addition, many of the early reports describe recently burnt buttongrass moorlands. These include J. Kelly in 1815, J. Goodwin in 1828, G. A. Robinson in 1830 and 1833, W. S. Sharland in 1832 and J. E. Calder in 1840 on Cape Sorell, Vale of Rasselas, along the south and west coasts of Tasmania, Port Davey, Loddon Plains, Wombat Glen and Navarre Plains (Kelly 1816), Goodwin 1828, Plomley 1966, 1991, Calder 1847, 1849, 1860a, b, c, Sharland 1861, also Gowlland & Gowlland 1976, Binks 1980). For example, in March 1828, J. Goodwin described what appears to be a patchwork of Aboriginal fires in the Vale of Rasselas (Goodwin 1828):

> near the Huon River [Gordon River in the Vale of Rasselas] we saw a number of native fires on the hills, and the grass appeared to have been burnt recently and frequently.

A similar situation was described by W. S. Sharland in 1832 near the upper Franklin River, when his party followed what he considered to be an Aboriginal track (Sharland 1861):

> We followed the said marsh [Painters Plain] and some burnt ground until it brought us out to a bare hill where a fire had been made by the blacks ...

As a result, the Aborigines must have been active, at least seasonally, throughout most of southwestern Tasmania in the early 1800s. Similar conclusions regarding Aboriginal land practices have also been made by Thomas (1993a, b).

An indication of just how open the country must have been in the 1820s and 1830s is also given by the speed at which the first Europeans moved across the country. At this time, such open country is highly unlikely to have been the result of European burning and is far more likely to be the result of thousands of years of Aboriginal fire management. For example, William Sharland in 1832 travelled from Lake Vera to near the present location of Bronte Park in two days (Sharland 1861) while Alexander McKay in 1830 travelled from Sarah Island to Elliott Bay

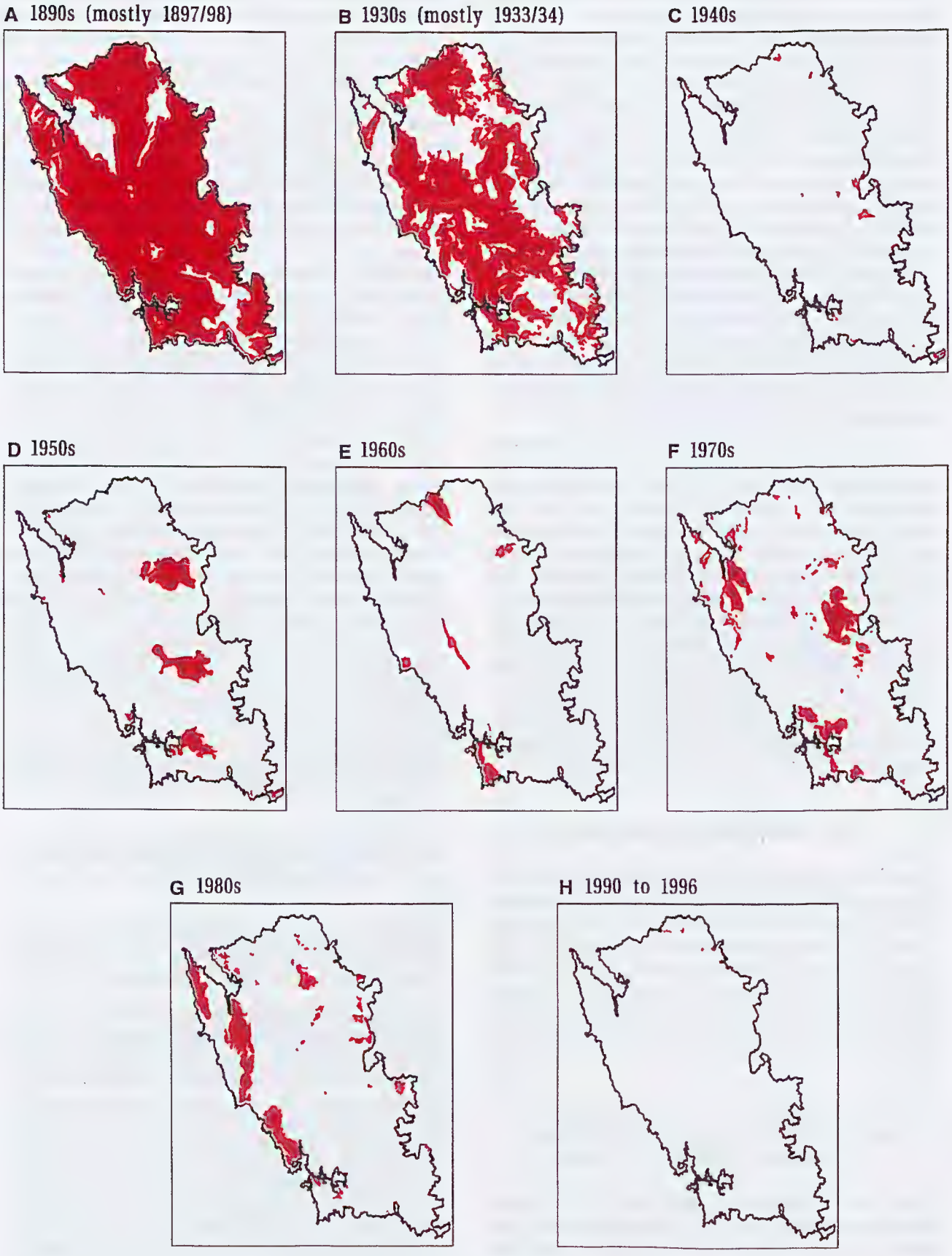


FIG. 1 — Area burnt in the 1890s and since the 1930s in southwestern Tasmania. Note: many of these fires also burnt very extensive areas in other parts of Tasmania.

in three days (Plomley 1966). In order to achieve such travelling times, the country must have consisted of a series of continuous or near continuous open young buttongrass moorlands. This is supported by the observations by G. A. Robinson in 1833 of the country between Birchs Inlet and Elliott Bay, where he described what appear to be eroded gullies and very open moorlands (Plomley 1966).

The proposed Aboriginal fire regime is one of mostly low-intensity fires under conditions when forested vegetation is too wet to burn. Although fires would have been lit in all seasons (Stockton 1982), in most cases, fires would probably have been restricted to spring, autumn and dry periods in winter. Fires were probably only lit in summer during wetter periods, when fires would have gone out when they burnt up to the moorland–forest boundary. This regime would have resulted in frequent low intensity moorland burns, only occasional fires in eucalypt forest and very few fires in rainforest and alpine vegetation. This regime must have been highly sophisticated and directed towards specific outcomes. The observations of G. A. Robinson on Bruny Island in April 1829, and near Nye Bay on Tasmania's west coast in March 1830 (Plomley 1966) and W. Sharland on the Loddon Plains in March 1832 (Sharland 1861) also support this regime.

The Aborigines also probably used fires to flush game when hunting and to create access tracks (Davies 1846, Roth 1899, Plomley 1966, 1991). There are also several reports describing recently burnt trees with only their bases fire-scarred (Thomas 1991). This would support the proposal that the Aborigines were lighting many small low-intensity fires rather than a few larger higher intensity fires.

This regime of low-intensity fires, mainly in spring and autumn, is analogous to the regime of firestick farming proposed by Jones (1969) and is similar to the fire regime currently being practised by Aborigines in Northern Australia (Jones 1995, Braithwaite 1995, Bowman 1995, also Plomley 1966, Stockton 1982, Binks 1980, Thomas 1991, Thomas & Hope 1994, Kohen 1995). In such a fire regime, the aim would probably have been to create a large number of small, recently burnt areas surrounded by thicker vegetation.

There are several ways in which the Aborigines could have achieved this control of fire. From the evidence presented by Thomas (1991), it appears that fires were normally lit under conditions when they would be of low intensity and would self-extinguish, although in some cases it appears that fires may have been beaten out using branches (Plomley 1966). This fire management technique is similar to that aimed for in the current low-intensity habitat-management burning regime (see Marsden-Smedley 1993a, b, Marsden-Smedley *et al.* 1998.).

Early European Fire Regime between 1830 and 1940

Following the removal of the Aborigines, it appears that initially few Europeans visited southwestern Tasmania (i.e. between about 1830 and 1850). During the 1830s to 1840s, exploration in southwestern Tasmania is only recorded from the middle Gordon River, Lake Pedder, Arthur Plains and upper Franklin River areas (Binks 1980). This was probably due to the small number of Europeans present in Tasmania at that time, the region's remoteness and official discouragement of exploration in order to maintain the isolation of the penal settlement at Sarah Island (Franks 1958, McRae 1960, Binks 1980). When compared to the fire frequencies and intensities utilised by the Aborigines, the low numbers of people visiting the region in the 1830s and 1840s would have resulted in a major reduction in fire frequency and a corresponding increase in fire size and intensity when fires did occur.

By about the 1850s and 1860s, there was an extensive network of tracks and routes, which allowed for the reopening up of the region (Cotton 1850, McRae 1960, Gowlland & Gowlland 1976, Binks 1980). Leading on from this opening up of the country was a major change in fire regime which resulted in the burning of the majority of southwestern Tasmania.

In the available literature, there are numerous references regarding the use of fire in southwestern Tasmania from this period. It appears that the normal method of moving through the region was to burn out a section of country, then follow the resulting easy path. In order to facilitate such burning, it appears that a large number of fires were lit in hot dry (and probably windy) weather, resulting in large, high-intensity fires in all vegetation types. This fire management regime is in marked contrast to the Aboriginal fire management practices.

The, earliest reports of Europeans lighting fires in southwestern Tasmania are probably by J. E. Calder and A. McKay in the middle Gordon River, Lake Pedder and Arthur Plains in March 1837 (Gowlland & Gowlland 1976). Calder's diary described their fires (Gowlland & Gowlland 1976):

> We burned the ground well filling the atmosphere with smoke ... Fired a vast tract of country ... never saw such a conflagration ...

Parts of the Southern Ranges between Mount Alexandra and Adamsons Peak were probably burnt in the first half of the 1800s (Perrin 1887). The damage caused by these fires was attributed to the effects of the 1837 frost by Perrin (1987, also Calder 1860a), but fire is a more likely explanation, due to the lack of observations of frost damage in other nearby areas which would be expected to be more susceptible, the distance from which the dead trees were observed (several kilometres) and the extremely frost-resistant nature of the species in question (*Athrotaxis* spp.) Fires also occurred in the Southern Ranges near Mt La Perouse in 1887/88 (*Mercury*, 11 January 1888), 1897/98 and 1933/34 (see pp. 20–21).

The Arthur, Huon and King William plains and areas in the Vale of Rasselas were burnt in 1850 by the Colonial Survey Office (Cotton 1850, 1851). In 1851, the first large-scale fire reported in southwestern Tasmania occurred. This fire burnt from the Pieman River to Maydena (Gilbert 1979). However, it is possible that the 1851 fire in fact occurred in 1850 and formed part of attempts to modify the region's buttongrass moorlands, such that they would be more suitable for sheep grazing.

In January to May 1859, H.T. Lewis and F. McPartlan led an extensive gold and other minerals search of the Davey River, Hardwood River, Crossing River, Lake Pedder and the south coast of Tasmania. During this time, despite the generally very wet weather, they lit a fire in moorland near the Davey and Hardwood Rivers (Lewis & McPartlan 1859). In March 1860, J.E. Calder lit large fires near Lake Pedder (Calder 1860c). These fires burnt with high intensities, probably because the area had not been burnt for many years (Lewis & McPartlan 1859).

The Loddon Plains were burnt, probably in 1857 by mineral prospectors (Tully 1859). Major fires also occurred in the valleys of the upper Franklin and Collingwood Rivers during W.A. Tully's prospecting expedition of January to March 1859 (Tully 1859). Tully's party in 1859 lit fires which burnt extensive areas, as described in his report of expedition (Tully 1859):

> The fire of the previous night had travelled far, burning a large extent of country, and was now raging violently behind us ... vast sheets of flames coming down like an avalanche scarcely one hundred yards distant, and roaring like the seas on a rock-bound shore ... The fires now burning on both sides of the river roared through the scrub, and sheets of flame danced in the thick forest below us, and swept the leaves off the highest trees in an instant ... The country was black for miles; not a speck of green could be seen, except the myrtle forest which clothed the side of Mount Gell.

Extensive burning was performed in the King River and Linda valleys by C. Gould's party in 1862, as described in his report (Gould 1862a):

> ... upon the 16th [February] proceeded along the plains bordering the Kings River, for a distance of six miles, firing them whenever possible .

The Arthur Plains were burnt in February and March of 1871 by J.R. Scott, W.C. Piguenit and F. McPartlan on their expedition to Port Davey. The 1871 fires were described by J. Hay in March 1871 (Hay 1871; also Scott 1871):

> I may mention that had it not been for Mr. Scott's fires running over and clearing a vast deal of the country, we would not have got over the extent of the ground we did in the time.

In l876, G. C. Meredith led a mineral exploration party to western Tasmania. Their party was prevented from landing at the Pieman River by heavy seas, and so they travelled overland from Macquarie Harbour. Whilst at Macquarie Harbour they lit fires on Cape Sorell (Meredith 1876).

In February to early March 1879, T. B. Moore burnt much of the country between Birchs Inlet and Port Davey (most of which consists of buttongrass plains). However, T. B. Moore's attempts in mid March and April of the same year to burn the country to the east of Port Davey, including the Crossing and Old River valleys were thwarted by the consistently wet weather.

Extensive fires were lit by track construction parties in the Lake Pedder, Serpentine River, Frankland Range, Rookery Plain and Olga River areas in 1881 and 1894 (Jones 1881, Innes 1896, Gowlland & Gowlland 1976, Binks 1980). For example, D. Jones whilst cutting a track from the lower Gordon River to the Huon River in 188l (Jones 1881):

> Took advantage of fine day and went ahead to look out best route and fire button-rush ... Whenever we could get a fine day we burned what we could, and the benefit to us was incalculable, rendering the travelling comparatively easy.

J.B. Walker, in his recreation trip of 1887 noted near the Franklin and Collingwood Rivers (Walker 1887, also Innes 1887):

> ... hill and valley densely wooded, save for lighter spots of open country, and variegated with reddish patches, the mark of extensive bushfires ... To the tourist it is exasperating to see the exquisite native beauty of these forests desecrated and turned into grim blackness by fires which during this hot summer have swept over so many miles of bush. But doubtless the prospector views it with other eyes, and after reading the graphic legend inscribed on a blazed tree at the foot of Mount Arrowsmith ... we were forced to admit that even these disfiguring fires might have their use in opening up the country, facilitating exploration and diminishing the hardships of these pioneers.

The fires near Frenchmans Cap, referred to by J. B. Walker in 1887, may have been the fires lit by T.B. Moore in February 1887, while cutting a route from the King River to Frenchmans Cap via the Governor River and Mt Finch (Moore 1887), where they

> ... sent James [Moore] out on the previous day ... to put a match into the country, which is clothed with button grass and tea tree ... We found the fire had done excellent work and was still blazing ahead ... The fires burnt for a week, and cleared the hated button grass and bauera splendidly, in all directions for miles.

Very extensive areas of the buttongrass moorland and wet scrub between Frodshams Pass on McPartlan's South Gordon Track and Joe Page Bay in Bathurst Harbour, along with forests on the slopes of Mt Bowes, were burnt in February 1898 (Marsden 1898). From the available information, it appears that these fires were not lit during the construction of the Port Davey Track by E.A. Marsden, but are part of a much larger series of fires which burnt very extensive areas throughout southwestern Tasmania that summer.

The 1897/98 fires in western and southwestern Tasmania were extensively reported on in the *Mercury* (e.g. 31 December 1897; 4, 6, 15 January 1898; 6, 10 February 1898) and in the *Tasmanian Mail* (e.g. 8, 15 January 1898; 19, 26 February 1898). The effects of these fires can also be seen in photographs which were taken between the 1890s and 1920s and are held in the Archives Office of Tasmania (Marsden-Smedley 1997). In total, the 1897/98 fires appear to have burnt much of the country between the West Coast Range, Hartz Mountains and the Southern Ranges (table 2). If so, then these would have been the largest fires in Tasmania's recorded history, with an area of about 1 000 000 ha within southwestern Tasmania (fig. 1A and see below, table 4).

Fires were also lit around Cox Bight and Melaleuca in 1898 by G.C. Meredith and his brother, during a mineral prospecting trip. These were unlikely to have been major fires, due to the generally wet weather preceding them.

In January to March 1900, T.B. Moore again led a party from Birchs Inlet to Port Davey and, in common with the 1879 trip, extensive fires were lit (Binks 1980, McShane 1982).

In March 1906, W.H. Tyler and W.T. Harper marked out a track along the south coast from Cockle Creek to Cox Bight. During this trip, they burnt Black Hole Plain and

reported that between Surprise Bay and Rocky Boat Inlet, the country had been fairly recently burnt, probably in 1897/98 (Tyler & Harper 1906).

In 1907/08, R. Marriott burnt extensive areas between the Vale of Rasselas and the Prince of Wales Range, including the Gell River, Mt Curly and the Denison River (Twelvetrees 1908; also Marriott 1908).

In December 1908, R.A.C. Thirkell cut a track from the Linda Track to the lower Franklin River, via the Loddon Plains, Calders Pass, Lightning Plains, Acheron River and Jane River. His report of the trackcutting noted (Thirkell 1908):

> My party have been able to fire the country well, and this will be of great assistance to the prospector next summer.

In 1933/34 there were very extensive fires on the Raglan Range, Loddon and Lightning Plains and near where the Frenchmans Cap Track leaves the Linda Track (*Mercury*, 3 March 1934, Thwaites 1934, Johnston 1935, Warren 1936, photographs in Philp 1937). In 1936, fires are reported to have been lit near Philps Lead and Lake Vera (Warren 1936), probably by piners and/or mineral exploration parties reopening J. L. Moore's 1900 and R.A.C. Thirkell's 1908 track to the Jane River (see also Abel n.d.). Warren (1936) also reported observing the smoke from fires near the Jane River, Raglan Range, Eldon Range and to the west (probably in the West Coast Range).

Between about the 1910s and 1930s, in marked contrast to the preceding 60 years, there was a major decrease in the amount of prospecting and exploration activity in southwestern Tasmania. The only significant exception to this decrease appears to be the development of the Adamsfield osmiridium field (Gowlland & Gowlland 1976) along with small mining fields at Cox Bight (Twelvetrees 1906), Melaleuca, Osmiridium Beach and the Jane River. This decrease in activity was probably due to the realisation that in southwestern Tasmania, with a few exceptions, the potential for significant mineral deposits and/or good agricultural land was very low. This reduction in exploration activity was reflected in the prospecting accounts of Twelvetrees (1908, 1909, 1915), Ward (1908, 1909) and Howard (1927), all of which reported that the access tracks had become very overgrown and blocked with fallen timber. The reduction in exploration activity was also reflected in the Department of Lands and Surveys annual reports for 1910 to 1932 (*Parliament of Tasmania Journals*). All these annual reports called for additional track construction to be performed, but all of them also reported that in southwestern Tasmania, no existing tracks had been cleared or new tracks constructed. Only five major tracks are known to have been cut during this period. Two of these tracks, Condor's 1915 west coast track and Hales' 1918 track, were cut by the Department of Mines. Condor's 1912 to 1915 west coast track went from Double Cove in Macquarie Harbour to the west coast near Albina Rock, and then south to Port Davey and north to Cape Sorell (Hills 1914, Condor 1915), while Hales' 1918 track went from the Gordon River to the Port Davey track (Hales 1918). In 1910, J. Philp marked out a track from the Linda Track to Frenchmans Cap via the Loddon Plains, Philps Lead and Lake Vera (Philp 1937). No official record appears to exist of the other two tracks which were put in during this period, except that they are shown on the 1960 sketch map of southwestern Tasmania (Department of Mines Tasmania 1960). Both of these tracks were located in the Weld River valley and linked the Huon River valley with the Port Davey Track, with one track linking via the upper Weld River valley and the other via the Snake River valley. The Snake River route is marked on the 1960 map as Giblin's 1924 route. The Weld River Track was originally cut by H. Judd and, subsequently, may have been recut by C. and D. King (who are better known as tin miners at Cox Bight and Melaleuca). This track was also used by a Mr Roberts to access the Jubilee Range for cattle grazing.

The prevailing sentiment of the 1800s and early 1900s appears to have been that it was advantageous to the prospector to burn sites in order to expose mineral strata, that fire would not hurt healthy forest, and that buttongrass moorlands could be transformed into more productive agricultural land by burning, sowing with pasture grasses and stocking with sheep and cattle. For example, the Chief Government Geologist, W.H. Twelvetrees, proposed in 1908 that areas of moorland, wet scrub and eucalypt forest (Twelvetrees 1908) could:

> ... be burned off in broad belts, and if this is done much track-making is unnecessary at first. The prospector can see by the line of burned country which way to follow; he can, moreover, get over the country easily, and prospect without difficulty where he desires. Money spent in burning the country in this way is well spent, and benefits the explorer even more than does the cutting of tracks (except of course through timber).

In 1860, J.E. Calder questioned whether fire would cause deleterious effects to the vegetation (Calder 1860a):

> ... do bush fires destroy the forests, or even seriously injure sound and living trees? and do we not see the contrary in a hundred cases every summer? If such indeed were the case we ought not to have a tree left in Tasmania.

C. Gould, in 1862, also held to the belief that buttongrass moorlands could be transformed, in that he proposed (Gould 1862a) that the extensive plains in the lower Gordon River and near Macquarie Harbour could

> ... afford moderate pasture, and are probably susceptible of the same improvement which is found to follow continuous burning and stocking in other parts of the Colony.

These attitudes are also reflected in the Colonial Survey Office reports. For example, H. Cotton in 1850 described the grazing potential of the buttongrass moorlands on the Arthur, Huon, King William Plains and in the Vale of Rasselas (Cotton 1850):

> The rough herbage upon these plains have been burnt for the encouragement of the grasses which are found to take its place, and in some parts, especially near Lakes Pedder and Edgar and in the Gordon Valley, the pasture is rich and luxuriant.

Such was the destruction of forest and other vegetation types by wildfires during this period that the issue was addressed by parliamentary reviews of the Tasmanian timber industry in 1887 and 1898 (e.g. Perrin 1887, 1898, Counsel 1898). For example, the Surveyor-General and Secretary for Lands, E.A. Counsel, reported (Counsel 1898) that

> ... one of the main points to which I desire to direct especial attention in this Report is the enormous consumption of valuable timber which is in process of being destroyed in the Mining Districts, particularly on the West Coast ... there is a wholesale and reckless destruction of the forest growth, young and old, by bush fires in all directions during many months of the year.

Counsel (1898) also called for changes in the policies for managing forested areas, including

> 3. That regulations be framed and especial care taken to protect young pine and other trees and plants from destruction.
> 4. That stringent measures be enacted for prohibiting the lighting of bush fires on unoccupied Crown Lands.

In the accompanying report on forest conservation and management by the Victorian Conservator of State Forests G.S. Perrin, these issues were reiterated in the strongest manner (Perrin 1898):

> The bush fires about Lyell, Zeehan, the Pieman and Lake Dora, &c. have already destroyed timber which it will cost shareholders in the mines many thousands of pounds more than they would otherwise have had to pay ...
>
> All through, however, indiscriminate felling and fierce bush fires have already destroyed large quantities of the useful timber I saw in this district [Zeehan and Mount Lyell] ten years ago, and have completely changed the face of the country.

Perrin (1898) also stated that fire protection in state forests was of the highest importance:

> This is a matter of urgent moment to the future of Tasmanian timber supplies ... A stringent Fire Act should be drafted with as little delay as possible ... The presence of the miner on the West Coast has, of course, resulted in the usual gross carelessness, and sometimes malicious vandalism, with which it has been associated elsewhere, and, unless the matter is dealt with promptly and vigorously, timber in this district for mining and other purposes will be completely exhausted within a very few years ... In order to clear prospecting claims it is quite an ordinary custom for the prospector to set fire to the timber and let the flames spread at will over as much of the surrounding country as they can reach.

As a result, large and/or high intensity fires burned across the majority of western and southwestern Tasmania. In particular, major fires are known to have occurred in 1851, 1897/98, 1914, 1933/34 and 1939, with numerous additional fires in other years. It should be noted, however, that the large areas burnt in these fires were probably the result of several smaller fires. The fires recorded between the 1830s and 1930s are shown in table 2, while the areas burnt in the 1890s and 1930s are shown in figure 1.

Some of these fires were very large, in particular the 1851, 1897/98 and 1933/34 fires. The 1851 fires are reported to have burned from the Pieman River to Maydena (a distance of over 150 km in a straight line — *Mercury,* 10 February 1939, Gilbert 1979). However, as already mentioned, it is possible that the 1851 fire occurred the previous year and formed part of the fires lit by the Colonial Survey Office which were aimed at opening up western Tasmania for sheep grazing (Cotton 1850). The 1897/98 fires burnt extensive areas near Queenstown, Frenchmans Cap, the Huon River, New River Lagoon and many other parts of southwestern Tasmania (see table 2, fig. 1A). The 1933/34 fires burned from the West Coast Range and the Lower Gordon River to Southport Lagoon (a distance of over 200 km in a straight line — fig. 1B). However, it has not been possible to map the northwestern part of the 1933/34 fires accurately (i.e. around the Raglan Range, Frenchmans Cap and Lightning Plains areas), since this area was reburnt in the much higher intensity 1938/39 fires.

The 1897/98, 1933/34 and 1939 fires all had periods of very high-intensity fire behaviour. For example, the 1933/34 fires caused darkness in Hobart between 4 and 5 pm on 9 February 1934 (*Mercury*, 10 February 1934), while the 1939 fires burned large areas of rainforest with crown fires (in contrast to most rainforest fires), which rarely burn more than about three-quarters of the forest canopy).

The map of the 1890s fires (most of which burned in 1897/98) shown in figure 1A was compiled from the information in table 2, newspaper and other historical records, site ages, historical photographs in the Archives Office of Tasmania and the author's personal knowledge of southwestern Tasmania. Since many of the areas burnt in the 1890s were also burnt in the 1933/34 and/or 1938/39 fires, it has not been possible to determine accurately the degree to which the different vegetation types were burnt in the 1890s fires (i.e. the relative proportions of burnt to unburnt areas within the fire's boundaries). Therefore, the fire boundaries shown in figure 1A and the areas shown as burnt in tables 3 and 4 should be taken only as a guide. For the purposes of this paper, within the area shown as burnt in the 1890s, reasonable estimates of the degree in which the different vegetation types burnt are about 95% for non-forest, about 90% for wet eucalypt forest and about 75% for rainforest, alpine and subalpine areas. For the same reason, (i.e. reburning by the 1930s fires) it has not been possible to map the fires of the 1900s, 1910s and 1920s. It should also be noted that the 1890s, 1933/34 and 1938/39 fires burned very extensive areas outside this project's study area.

These very large fires would best be described as landscape-scale fires, in that they burnt very extensive areas, probably taking several weeks to months to do so. Landscape-scale fires appear to have only been contained by major geographic boundaries, such as the major rivers and/or large areas of rainforest, especially those on the lee sides of mountain ranges and/or the coast.

The landscape-scale fires during this period were probably responsible for the destruction of extensive areas of highly fire-sensitive coniferous forest and heath that have been burnt since European settlement in Tasmania (*Mercury*, 4 Jan. 1898, Perrin 1898; also Brown 1988, Peterson 1990, Robertson & Duncan 1991). These fires may also have had major impacts on the region's peat soils (Pemberton 1988, 1989, Hannan *et al.* 1993, Pemberton & Cullen 1995).

TABLE 2
Recorded fires in western and southwestern Tasmania between the 1820s and 1930s

Location	Date	Major fire*	Reference
Aboriginal fires			
Vale of Rasselas	1828	no	Goodwin 1828
Port Davey, Lower Hut Plains, Nye Bay	1830	no	Plomley 1966
Loddon Plains	1832	no	Sharland 1861
Birchs Inlet–Elliott Bay	1833	no	Plomley 1966
European fires			
middle Gordon R., L. Pedder, Arthur Plains	1837	yes	Gowlland & Gowlland 1976
Mt Alexandra to Adamsons Peak	early 1800s	?	Perrin 1887
Loddon Plains	1849?	?	Tully 1859
Arthur, Huon and King William Plains	1850	?	Cotton 1850, 1851
Vale of Rassalas	1850	?	Cotton 1850, 1851
Pieman River to Maydena	1851	yes	*Mercury* 10-2-1934, 1-2-1939
Hardwood River, Davey River	1859	no	Lewis & McPartlan 1859
upper Franklin and Collingwood Rivers	1859	yes	Tully 1859
Lake Pedder, Frankland Range, Hardwood River	1860	?	Calder 1860c
King River and Linda Valley	1861/62	yes	Gould 1862a
Arthur Plains	1870/71	?	Hay 1871, Scott 1871
Cape Sorell	1876	?	Meredith 1876
Birchs Inlet to Port Davey	1878/79	no	Binks 1980, McShane 1982
Lake Pedder, Frankland Range, Hardwood River	1881	no	Jones 1881
D'Entrecasteaux River	1886/87	no	Perrin 1887
King River, Mt Fincham, Frenchmans Cap	1887	yes	Moore 1887
upper Franklin and Collingwood Rivers	1887/88	yes	Innes 1887, Walker 1887
Mt La Perouse	1887/88	?	*Mercury* 11-01-1888
Lake Pedder, Frankland Range, Hardwood River	1894	no	Innes 1896
Mt Bowes, Arthur Plains, Huon River	1897/98	yes	Marsden 1898
Crossing and Spring Rivers, Melaleuca	1897/98	yes	Marsden-Smedley 1997
Southwest Cape Range, Cox Bight	1897/98	yes	Marsden-Smedley 1997
Mt Bobs–Boomerang	1897/98	yes	Kirkpatrick & Harwood 1980
Lake St Clair	1897/98	yes	*Mercury* 6-01-1898
Queenstown, Zeehan, Strahan, Tyndall Range	1897/98	yes	*Mercury* 4-01-1898
Raglan Range, King River, Mt Owen, Mt Lyell	1897/98	yes	Ward 1908
Lake Vera, Philps Peak	1897/98	yes	Philp 1937
Flat Rock Plain	1897/98	yes	Marsden-Smedley 1997
Surprise Bay, Tylers Creek, Rocky Boat Inlet	1897/98	yes	Tyler & Harper 1906
Menzies Bluff	1897/98	yes	Marsden-Smedley 1997
Pindars Peak, Gordon Gorge, Hartz Mtn	1897/98	yes	Archives Office of Tasmania photo
Mt Read, Mt Darwin, L. Margaret, Queenstown	1897/98	yes	Archives Office of Tasmania photo
Cox Bight–Melaleuca	1898	no	Meredith 1898
Birchs Inlet to Port Davey	1899/1900	no	Binks 1980, McShane 1982
Black Hole Plain	1905/06	no	Tyler & Harper 1906
Gell River, Mt Curly, Denison River	1907/08	no	Twelvetrees 1908
Jane River, Lightning Plains?, Loddon Plains?	1907/08	no	Thirkell 1908
Raglan Range, Loddon and Lightning Plains	1933/34	yes	Thwaites 1934, Johnston 1935
Linda and Frenchmans Cap Tracks junction	1933/34	yes	Philp 1937
Loddon Plains, Lake Vera, Raglan Range	1935/36	?	Warren 1936
Eldon Range, Jane River	1935/36	?	Warren 1936
West Coast Range, Frenchmans Cap	1938/39	yes	B. Bradshaw, pers. comm.

* Major fire: yes = large and/or high intensity fire, no = small and/or low intensity fire, ? = fire size and/or intensity unknown.

Fire Regime between 1940 and 1970

Between about 1940 and 1970 another change in the fire regime appears to have occurred. During this time fires were generally small, with the notable exceptions of three fires in the 1950s (i.e. the Old River, Spires and Lake Pedder fires; fig. 1C). Two of these large fires were lit by mineral exploration parties (i.e. Old River Fire, *Mercury*; Lake Pedder Fire, D. Pinkard, pers. comm.). The cause of the Spires fire is unknown, but mineral exploration parties were active in this area at this time (*Mines Department Annual Reports* for 1950 to 1953). Another major change in fire

TABLE 3
Fire regimes during different periods in southwestern Tasmania

	Vegetation assemblage							
	Moorland		Wet scrub		Wet eucalypt forest		Rainforest	
Period	Frequency	Intensity	Frequency	Intensity	Frequency	Intensity	Frequency	Intensity
Aboriginal, pre-1830	high	low	med	med	low	high	low	high
early European, 1830/1940	high	high	high	high	high	high	high	high
middle European, 1940/70	low	low/med	low	med	low	high	low	high
current, post 1970	low	variable	low	med	low	high	low	high

TABLE 4
Area of different vegetation types burnt in the 1890s and since the 1930s

	Vegetation assemblage								
	Moorland and wet scrub		Wet eucalypt forest		Rainforest		Subalpine and alpine		Total
Period	ha	%	ha	%	ha	%	ha	%	ha
estimated 1890s	690 676	90.3	188 516	83.3	94 192	38.3	25 913	50.3	999 296
1930s	489 625	64.0	51 161	22.6	59 364	24.1	28 906	56.1	629 056
1940s	8 257	1.1	2 158	1.0	356	0.1	80	0.2	10 851
1950s	71 384	9.4	4 755	2.1	5 096	2.1	2 497	4.8	83 732
1960s	25 743	3.4	3 860	1.7	3 739	1.5	394	0.8	33 736
1970s	92 349	13.1	7 835	3.5	4 649	1.9	390	0.8	105 223
1980s	88 947	12.6	8 307	3.7	7 595	3.1	379	0.7	105 228
1990 to 1996	380	0.1	456	0.2	142	0.1	19	0.0	997
Total burnt	1 467 361	-	267 048	-	175 133	-	58 578	-	1 968 119

Note: the area of different vegetation types has changed since the 1950s, due to the effects of inundation for hydro-electric schemes. Current area of the different vegetation types shown. % burnt in each decade = the % of the total area of each vegetation type and not the % of the total area burnt. See Marsden-Smedley 1997 for the total area of each vegetation type. Areas burnt in the 1890s corrected for the amount that each vegetation type is estimated to have burnt (see text).

regime during this period is a change to primarily moorland fires, with little forest being burnt (table 4). This change in fire regime is probably the result of changes in cultural attitudes, whereby southwestern Tasmania began to be valued more for its natural assets and less for its mineral and grazing potential; therefore, fewer fires were being lit. The fire regime during the 1940s to 1960s would most probably have been one of mostly medium intensity fires in spring and autumn, mainly in moorland communities.

Post 1970 Fire Regime

Since the 1970s, there has been a shift to a combination of prescribed burns in selected areas of buttongrass moorland and, effectively, a fire exclusion policy (including the suppression of wildfires) across the rest of the region (Parks and Wildlife Service 1997). It should be noted that there have been marked reductions in the area burnt in prescribed fires in the past decade (table 4). The end result of these practices has been the maintenance of young moorlands in the Lyell Highway, Birchs Inlet, Elliott Bay, Port Davey, Melaleuca and Cox Bight regions, and the development of old-growth moorlands and wet scrub across most of the rest of the area. In common with the period 1940 to 1970, few forest fires occurred. The majority of the fires during this period were low intensity, although some fires did have short periods of medium-intensity fire behaviour. For example, the Birchs Inlet and Mulcahy Bay fires both burned about half of the total area during the final afternoon of fire run, resulting about 30 000 ha being burnt out in two four-hour periods (i.e. 25% of the total area burnt between 1980 and 1995/96, burned during about eight hours). The fire regime in the post 1970 period would most probably have been one of mostly low-intensity fires in moorland communities in autumn and spring.

Fire Regimes and Area Burnt in Different Time Periods

As discussed above, major changes in fire regime of southwestern Tasmania have occurred over about the last 170 years. The fire regime has probably gone from one of frequent low-

intensity fires in the moorlands with only the occasional high-intensity forest fire, to one of frequent moderate to high-intensity fires in all vegetation types, to low to medium-intensity moorland fires (see also fig. 1).

It should also be noted that there were probably few fires between about the 1830s and 1851, and between 1897/98 and the 1930s. Although there was a considerable number of fires between the 1850s and 1890s (table 2), it is probable that the majority of the region was left unburnt. The deduced fire regimes during different periods are shown in table 3.

There have been marked changes in the area of different vegetation types burnt since the 1890s and 1930s. As can be seen in table 4 large amounts of all of the different vegetation types were burnt in the 1890s and 1930s but, since the 1930s, few wet eucalypt forest, rainforest, subalpine and alpine areas have been burnt.

The relatively small area burnt in the 1940s is possibly a reflection of the very extensive 1930s fires, which would have resulted in much of the region consisting of regrowth vegetation in the 1940s (and hence being less flammable). The area of moorland burnt in the 1950s is almost entirely the result of three fires. The effects of the change in fire regime in the 1970s, with the introduction of extensive hazard-reduction burns, and equally the reduction in the area burnt in these hazard-reduction burns in the early 1990s can also be seen in table 4. The large area of moorland burnt in the 1980s is mainly the result of two fires, which together burnt more than 60 000 ha (Blanks 1991).

Another effect of the reduction in the area burnt since the 1930s is the formation of very extensive areas of old-growth moorland. This is because, in southwestern Tasmania, the majority of non-forested lowland vegetation types consist of buttongrass moorland, and more than 75% of these areas are more than 35 years of age (see Marsden-Smedley 1997; also table 5). The age categories in table 5 are based on the time required for selected moorland species to set seed (Marsden-Smedley 1990) and on the dynamics of moorland fuel accumulation and fire behaviour (Marsden-Smedley 1997). This increase in fire age is not restricted to buttongrass moorland vegetation types and is occurring in all of the region's vegetation assemblages.

EFFECT OF CHANGES IN THE FIRE REGIME OF SOUTHWESTERN TASMANIA

As discussed above, there have been major changes in the fire regime of southwestern Tasmania over about the last 170 years. These changes are unlikely to be the result of climatic changes since, with the exception of the last 25 years (which has been drier than the previous about 150 years, and during which time no major fires occurred in southwestern Tasmania), the climate over the last 170 years has not been unusual when compared to the previous several thousand years (Cook *et al.* 1992, 1996). It should also be noted that comparable conditions to those that occurred in 1897/98 and 1933/34 occur about every five to ten years (Bureau of Meteorology data). As a result, these changes in fire regime are probably a reflection of changes in cultural attitudes and technology.

The aim of the Aboriginal fire management regime would have been to modify the environment to be more suitable for their utilisation. As such, it should be noted that the Aboriginal burning regime was not a natural or hazard-reduction burning regime, but rather it was closer to a habitat-management regime. It should also be noted that the generally slow rate of vegetation succession in southwestern Tasmania would mean that the distribution of the majority of the current vegetation and soil types would be the result of Aboriginal land use practices. Therefore, the current distribution of vegetation and soils in this region should not be described as "natural", and a better description would be a cultural landscape.

Considerable information as to the characteristics of the Aboriginal fire regime can also be gained from observations of the dynamics of peat formation and vegetation distributions in southwestern Tasmania. Conditions have been suitable for peat formation in southwestern Tasmania for about the past 10 000 to 12 000 years (Thomas 1995), with the formation of peat soils requiring 3000 to 12 000 years at a rate of about 10–20 mm per century (Pemberton & Cullen 1995). However, due to differences in fuel moisture, fires tend to burn different amounts and types of fuel in different seasons. Spring and autumn fires normally leave a mat of unburnt thatch (often consisting of the majority of the lower parts of the fuel array), in contrast to summer fires, which typically burn most of the fuel array (Marsden-Smedley 1997). In addition, if fires occur in dry summers, the peat itself may burn (Bowman & Jackson 1981, Marsden-Smedley 1993a). One effect of this is that significant peat formation is unlikely to occur in a regime of summer fires, due to the lack of suitable peat precursor material and the high probability that any pre-existing peat will be burnt.

The coexistence of extensive areas of buttongrass moorland in close proximity to highly fire-sensitive rainforest and alpine heaths also supports the proposal that the Aborigines must have had a tradition of lighting fires when wet scrub and forest communities were too wet to burn. This is especially the situation with rainforests and heaths containing coniferous species such as King Billy pine *(Athrotaxis selaginoides),* Huon pine and pencil pine *(Athrotaxis cupressoides).* Due to the time periods required for successional processes (Jackson 1968, Jarman *et al.* 1988b, Marsden-Smedley 1990) and soil formation (see above), these communities must have coexisted for thousands of years.

The fire management aim of the early Europeans was very different. Their aim was to open up the country in order to expose potential mineral deposits, improve access and to make the vegetation more economically productive. It should also be noted that the early European fire regime was almost certainly non-sustainable and was probably only maintained through the burning off of the fuel and

TABLE 5
Area of lowland non-forested vegetation in different age categories

Category	Age, years	Area	
		ha	%
Regrowth	less than 15	89 247	12.7
Mature	15 to 35	80 693	11.5
Old-growth	greater than 35	534 239	75.9

Note: the majority of lowland non-forest vegetation in southwestern Tasmania is buttongrass moorland.

soil nutrient capital which had accumulated during periods of lower fire frequencies. Evidence of this can be seen in the aerial photographs from the 1940s, where there are extensive areas of what appear to be degraded moorland, scrub and forest. As a result of this extensive burning, the early European fire regime would have caused massive vegetation change. For example, 32% of King Billy pine, 8% of Huon pine and a significant amount of deciduous beech *(Nothofagus gunnii)* were destroyed by fire during this period (Brown 1988, Peterson 1990, Robertson & Duncan 1991). There may also have been extensive areas of peat soils destroyed during this time (Pemberton 1988, 1989, Hannan *et al.* 1993, Pemberton & Cullen 1995). However, the observation that extensive areas of peat soils have been lost due to European burning needs to be made with caution, since there is no quantitative evidence that the areas which currently have gravel soils ever had more extensive organic soils. This is reflected in the observations of extensive areas of gravel soils by G. A. Robinson on the south and west coasts and near the Wanderer River (Plomley 1966), J. E. Calder near the Acheron River (Calder 1849) and J.R. Scott on the Arthur and Crossing Plains and near Port Davey (Scott 1871, 1875). Therefore, it is possible that a proportion of the skeletal soils in western and southwestern Tasmania could be a product of the region's low fertility, past glacial events and/or Aboriginal fires.

It should also be noted that once rainforests have been burnt, major changes occur to their fuel arrays such that they become far more flammable. This is mainly due to increases in the amount of dead fuel, opening up of the canopy and changes to the floristics and structure of the community (Barker 1991).

In parallel to the changes reported in this paper, major changes in fire regime, resulting from changes in cultural and land-use practices, have also been reported in the rainforests, woodlands and grasslands of Patagonia. In this area, prior to the 1890s, the indigenous Indians practised a fire regime of frequent low-intensity fires in the xeric woodlands and grasslands with few fires in rainforests. Following the removal of the Indians in the 1890s, European settlers introduced widespread fire to the region's rainforests in an attempt to transform the forest into grassland for the purposes of cattle ranching. Again in common with southwestern Tasmania, the success of the European's attempts to burn the rainforest communities was largely dependent on the degree of seasonal drought, with major fires occurring in the drought years of 1911 to 1917 (Kitzberger *et al.* 1997).

Southwest Tasmania is an area of very high cultural and ecological value, as evidenced by its World Heritage Status. Therefore, the management of the region must be targeted to maximise the positive aspects of the management regime whilst minimising the negative impacts. The *Tasmanian Wilderness World Heritage Area Draft Management Plan* (Parks & Wildlife Service 1997) states that the overall main management objectives are

> To identify, protect, conserve, present and, where appropriate, rehabilitate the natural and cultural values of the World Heritage Area, and to transmit that heritage to future generations in as good or better a condition than at present.

A regime of natural (i.e. lightning) fires is not going to meet these goals. This is because the slow rates of vegetation succession in southwestern Tasmania result in very long fire-free periods being required, in order to transform the vegetation to the less flammable rainforest community types. Infrequent fire would also result in the fire-adapted vegetation of the region being classified as old-growth, with the attendant problems of high fuel loads, high dead to live fuel ratios and highly continuous fuels. Under a regime of infrequent fires, when the inevitable summer fire occurred in fire-adapted vegetation, the characteristics of the fuel array would ensure that the fire had higher rates of fire spread and intensities than is normal. Such fires would also have a high probability of burning peat soils and transgressing natural boundaries and, therefore, burning fire-sensitive vegetation.

As a result, if we are to maintain and enhance the biodiversity of the wildlands of western and southwestern Tasmania, we are going to have to reintroduce fire into many of the areas which currently have a low fire frequency. However, when fire is reintroduced to these areas, it is absolutely essential that the fire regime implemented is in keeping with the ecological requirements of the vegetation being burnt. The alternative policy of not performing prescribed burning and allowing natural fires to burn (i.e. similar to the policy applying in some of the USA wilderness — Leopold *et al.* 1963, Kilgore 1985, Schullery 1989) is unlikely to be effective in southwestern Tasmania. Such a policy of benign neglect (Brown 1996) will not provide an adequate number of fires to maintain fire-adapted vegetation types whilst protecting fire-sensitive vegetation types. Such a policy will also require a high degree of fatalism (Blanks 1991), since it will almost certainly lead to a repeat of the situation that occurred in the 1850s, 1890s and 1930s, when very extensive areas of fire-sensitive vegetation were burnt.

The situation where there is a requirement for the re-introduction of fire into fire-adapted vegetation is not unique to western and southwestern Tasmania. Many other parts of the world have similar ecological problems. In northern America, over the past decade, there has been an increasing push for the restoration of wildland vegetation, often using fire (e.g. Schullery 1989, Brennan & Hermann 1994, Mutch 1994). These strategies have both ecological and economic advantages. Therefore, in order to manage southwestern Tasmania adequately, we are going to have to be pro-active and dynamic in our management. If we follow such guidelines, then we have a reasonable chance of being able to maximise our gains whilst minimising our impacts. Not to do so, is almost certainly to degrade our wildland environment, whilst incurring increased economic costs.

ACKNOWLEDGEMENTS

This research was supported by the Department of Geography and Environmental Studies, University of Tasmania, and the Fire Management Branch, Parks and Wildlife Service, Department of Environment and Land Management, Tasmania. In particular, I would like to acknowledge the assistance of Dylan Kendall, who coaxed the maps out of the Geographic Information System, along with Jamie Kirkpatrick and Mick Brown, who provided critical comments on the work performed in this paper. The considerable assistance obtained from the staff at the Archives Office of Tasmania and the Royal Society of Tasmania archives is also acknowledged.

REFERENCES

ABEL, G., no date: *AGAINST THE GRAIN: WITH THE HUON PINE LOGGERS OF THE WEST COAST OF TASMANIA.* The Printing Press.

BARKER, M.J., 1991: The effect of fire on west coast lowland rainforest. *Tech. Rep. Tasm. NRCP 7.* Forestry Commission, Hobart, Tasmania, and DASETT, Canberra, ACT.

BELL A., 1983: Fire and rainforest in Tasmania. *Ecos* 37: 3–8.

BINKS, C.J., 1980: *EXPLORERS OF WESTERN TASMANIA.* Mary Fisher Bookshop, Launceston, Tasmania.

BLANKS, T., 1991: Fatalism: a cost effective approach to fire management in Southwest Tasmania. *In FIFTH REGIONAL SEMINAR ON NATIONAL PARKS AND WILDLIFE MANAGEMENT TASMANIA,* 1991. Department of Parks, Wildlife and Heritage, Hobart, Tasmania.

BOWMAN, D.M.J.S., 1995: Why the skilful use of fire is critical for the management of biodiversity in Northern Australia. *In* Rose, D.B. (Ed.): *COUNTRY IN FLAMES. Proceedings of the 1994 symposium on biodiversity and fire in North Australia.* Biodiversity Series, Paper No. 3. Biodiversity Unit, Department of the Environment, Sport and Territories, Canberra, Australia and the North Australia Research Unit, Australian National University, Canberra, Australia.

BOWMAN, D.M.J.S. & JACKSON, W.D., 1981: Vegetation succession in Southwest Tasmania. *Search* 12: 358–362.

BRAITHWAITE, R.W., 1995: A healthy savanna, endangered mammals and Aboriginal burning. *In* Rose, D.B. (Ed.): *COUNTRY IN FLAMES. Proceedings of the 1994 symposium on biodiversity and fire in North Australia.* Biodiversity Series, Paper No. 3. Biodiversity Unit, Department of the Environment, Sport and Territories, Canberra, Australia and the North Australia Research Unit, Australian National University, Canberra, Australia.

BRENNAN, L.A. & HERMANN, S.M., 1994: Prescribed fire and forest pests: solutions for today and tomorrow. *J. For.* 92: 34–37.

BRIDLE, K.L. & KIRKPATRICK, J.B., 1997: Local environmental correlates of variability in the organic soils of moorland and alpine vegetation, Mt Sprent, Tasmania. *Aust. J. Ecol.* 22: 196–205.

BROWN, M.J., 1988: *DISTRIBUTION AND CONSERVATION OF KING BILLY PINE.* Forestry Commission, Hobart, Tasmania.

BROWN, M.J., 1996: Benign neglect and active management in Tasmania's forests: a dynamic balance or ecological collapse? *For. Ecol. Manage.* 85: 279–289.

BURN, D., 1842: Narrative of the overland journey of Sir John and Lady Franklin and party from Hobart Town to Macquarie Harbour. *In* Mackaness, G. (Ed.): *Aust. Hist. Monogr.* XVI (new series), published 1977.

CALDER, J.E., 1847: Copy of a letter of Mr J E Calder upon the existence of natives in unexplored parts of Tasmania in 1847. RS 19/6, Royal Society of Tasmania Archives.

CALDER, J.E., 1849: Some account of the country lying between Lake St Clair and Macquarie Harbour. *Tasm. J. Nat. Sci., Agric., Stat.* 3: 415–429.

CALDER, J.E., 1860a: Topographical sketches of Tasmania. Number 3. *Mercury,* 27 Jan. 1860.

CALDER, J.E., 1860b: Topographical sketches of Tasmania. Number 5. *Mercury,* 6 Mar. 1860.

CALDER, J.E., 1860c: Exploration. Some account of the country between Hamilton and Lake Pedder. *Mercury,* 13 Apr. 1860.

CONDOR, H., 1915: The wild west. Port Davey to Macquarie Harbour. One hundred miles of track. *Mercury,* 31 Mar. 1915.

COOK, E.R., BIRD, T., PETERSON, M., BARBETTI, M., BUCKLEY, B., D'ARRIGO, R. & FRANCEY R., 1992: Climatic change over the last three millennium in Tasmania reconstructed from tree-rings. *Holocene* 2: 205–217.

COOK, E.R., BUCKLEY, B. & D'ARRIGO, R., 1996: Inter-decadal climate oscillations in the Tasmanian sector of the Southern Hemisphere: evidence from tree rings over the last three millennia. *In* Jones, P.D., Bradley, R.S. & Jouzel, J. (Eds): *CLIMATE VARIATIONS AND FORCING MECHANISMS OF THE LAST 2000 YEARS.* NATO ASI vol. 141.

COSGROVE, R., ALLEN, J. & MARSHALL, B., 1994: Late Pleistocene human occupation in Tasmania: reply to Thomas. *Aust. Archaeol.* 38: 28–35.

COTTON, H., 1850: Report on access routes and pasture land in southwest Tasmania. Colonial Survey Office, Tasmania. CSO 24/130/4347/368-372, Archives Office of Tasmania.

COTTON, H., 1851: Government Notice No. 38. General report on the progress of operations west of the Derwent. *Hobart Town Gazette,* 8 Apr. 1851.

COUNSEL, E.A., 1898: Timber industry in Tasmania. *Parliament Tasm. J.* 1898, report 48.

DAVIES, R.H., 1846: On the Aborigines of Van Diemans Land. *Tasm. J. Nat. Sci., Agric. Stat.* 2: 409–420.

DEPARTMENT OF MINES TASMANIA, 1960. *SOUTH WEST TASMANIA.* 1:158 400 sketch map.

FLANAGAN, R., 1985: *A TERRIBLE BEAUTY. HISTORY OF THE GORDON RIVER COUNTRY.* Greenhouse Publications Pty Ltd, Melbourne, Victoria.

FRANKLAND, G., 1835: Account of a trip to the middle Gordon and Huon River plains. *Hobart Town Courier,* 27 Mar. 1835.

FRANKLAND, G., 1836: Account of tracks to Lake St Clair and the Huon River. *Hobart Town Courier,* 15 July 1836.

FRANKS, S.M., 1958: Land exploration in Tasmania, 1824-1842 with special reference to the Van Diemen's Land Company. Unpubl. MA thesis, Univ. Tasm.

GILBERT, J.M., 1978: Notes on forest classification and fire occurrence. Lower Gordon Environmental Investigation. Unpubl. rep. Hydro Electric Commission, Hobart, Tasmania.

GILBERT, J.M., 1979: Fires in the Tasmanian bush. *Tasm. Tramp* 23: 118-122.

GOODWIN, J., 1828: *Goodwin's statement.* CSO 1/276/6658, Archives Office of Tasmania.

GOULD, C., 1862a: Macquarie Harbour. Mr. Gould's report. *Legislative Council J.*vol. VII, rep. 20, Hobart, Tasmania.

GOULD, C., 1862b: Safety of Mr. Gould's party. Discovery of a gold field and valuable mineral country. *Mercury,* 14 May 1862.

GOWLLAND, R. & GOWLLAND, K., 1976: *TRAMPLED WILDERNESS. THE HISTORY OF SOUTH-WEST TASMANIA.* Third edn, 1986. Richmond Printers, Devonport, Tasmania.

HALES, R.C., 1918: Unpublished track report: Exploration of Gordon–Tyenna track. NP 21/14, Archives Office of Tasmania.

HANNAN, D.G., BANKS, M.R., KIERNAN, K., PEMBERTON, M. & WILLIAMS, E., 1993: Physical environment - geology, geomorphology and soils. *In* Smith, S.J. & Banks, M.R. (Eds): *TASMANIAN WILDERNESS – WORLD HERITAGE VALUES.* Royal Society of Tasmania, Hobart, Tasmania.

HAY, J., 1871: Exploration trip to the west. *Mercury,* 24 Mar. 1871.

HILLS, L., 1914: Geological reconnaissance of the country between Cape Sorell and Point Hibbs. *Geological Survey Bulletin* 18. Department of Mines, Hobart, Tasmania.

HOWARD, C., 1927: Notes on the country between Low Rocky Point and Fitzgerald. Report of the Director of Mines. *Parl. Tasm. J.* 1927, rep. 4.

INNES, E.G., 1887: The Derwent Valley Track to Linda. *Tasm. Mail*, 29 Jan. 1887.

INNES, E.G., 1896: Route to the west coast: Report of Mr. Surveyor Innes upon the country between Mount Humboldt and the head of the navigable water upon the River Gordon. *Parl. Tasm. J.* 1896, rep. 74.

JACKSON, W.D., 1968: Fire, air, water and earth — an elemental ecology of Tasmania. *Proc. Ecol. Soc. Aust.* 3: 9–16.

JACKSON, W.D., 1981: *THE VEGETATION OF TASMANIA.* Botany Department, University of Tasmania.

JARMAN, S.J., KANTVILAS, G. & BROWN, M.J. 1988a: A preliminary study of stem ages in buttongrass moorlands. *Res. Rep.* 3, Tasmanian Forest Research Council Inc., Hobart, Tasmania.

JARMAN, S.J., KANTVILAS, G. & BROWN, M.J., 1988b: Buttongrass moorland in Tasmania. *Res. Rep.* 2, Tasmanian Forest Research Council Inc., Hobart, Tasmania.

JOHANNES, C.E. & BROWN, A.V., 1992: *W.C. PIGUENIT 1836–1914 RETROSPECTIVE.* Tasmanian Museum and Art Gallery, Hobart, Tasmania.

JOHNSTON, B., 1935: To the Jane River. *Tasm. Tramp* 4: 5-12.

JONES, D., 1881: Report on track from Macquarie Harbour to upper Huon. *Parl. Tasm. J.* 1881, report 126.

JONES, R., 1969: Fire stick farming. *Aust. Nat. Hist.* 16: 224–228.

JONES, R., 1993: Discovery of a Pleistocene world. *In* Smith, S.J. & Banks, M.R. (Eds): *TASMANIAN WILDERNESS — WORLD HERITAGE VALUES.* Royal Society of Tasmania, Hobart, Tasmania.

JONES, R., 1995: Mindjongork: legacy of the firestick. *In* Rose, D.B. (Ed.): *COUNTRY IN FLAMES. Proceedings of the 1994 symposium on biodiversity and fire in North Australia.* Biodiversity Ser., Pap. 3. Biodiversity Unit, Department of the Environment, Sport and Territories, Canberra, Australia and the North Australia Research Unit, The Australian National University, Canberra, Australia.

KELLY, J., 1816: First discovery of Port Davey and Macquarie Harbour. *Pap. Proc. Roy. Soc. Tasm.* 1920.

KIERNAN, K., JONES, R. & RANSON, D., 1983: New evidence from Fraser Cave for glacial age man in south-west Tasmania. *Nature* 301: 28–32.

KILGORE, B.M., 1985: The role of fire in wilderness: a state-of-knowledge review. *In* Lucas, R.C. (Ed.): *Proceedings of the National Wilderness Research Conference.* USDA Forest Service General Tech. Rep. INT-220. Intermountain Forest and Range Experimental Station, Ogden Utah, USA.

KIRKPATRICK, J.B., 1982: Phytogeographical analysis of Tasmanian alpine floras. *J. Biogeogr.* 9: 255-271.

KIRKPATRICK, J.B., 1984a: Altitudinal and successional variation in the vegetation of the northern part of the West Coast Range, Tasmania. *Aust. J. Ecol.* 9: 81-91.

KIRKPATRICK, J.B., 1984b: Tasmanian high mountain vegetation II - Rocky Hill and Pyramid Mountain. *Pap. Proc. Roy. Soc. Tasm.* 118: 5-20.

KIRKPATRICK, J.B. & BROWN, M.J., 1987: The nature of the transition from sedgeland to alpine vegetation in south-west Tasmania. I. Altitudinal vegetation change on four mountains. *J. Biogeogr.* 14: 539-549.

KIRKPATRICK, J.N. & HARWOOD, C.E., 1980: Vegetation of an infrequently burned Tasmanian mountain region. *Proc. R. Soc. Vict.* 91: 79–107.

KIRKPATRICK, J.B. & BROWN, M.J., 1991: *RESERVATION ANALYSIS OF TASMANIAN FORESTS.* Resource Assessment Commission Forest and Timber Inquiry Consultancy Series No. FTC91/16.

KIRKPATRICK, J.B., NUNEZ, M., BRIDLE, K. & CHLADIL, M.A., 1996: Explaining a sharp transition from sedgeland to alpine vegetation on Mt Sprent, southwest Tasmania. *J. Veg. Sci.* 7: 763-768.

KITZBERGER, T., VEBLEN, T.T. & VILLALBA, R., 1997: Climatic influences on fire regimes along a rain forest-to-xeric woodland gradient in northern Patagonia, Argentina. *J. Biogeogr.* 24: 35–47.

KOHEN, J.L., 1995: *ABORIGINAL ENVIRONMENTAL IMPACTS.* University of New South Wales Press, Sydney, Australia.

LEOPOLD, A.S., CAIN, S.A., COTTAM, C.M., GABRIELSON, I.N. & KIMBALL, T.L., 1963: Wildlife management in the national parks. *Trans. North Am. Wildland Nat. Resour. Conf.* 24: 28–45.

LEWIS, H.T. & MCPARTLAN, F., 1859: Diary of Mr Henry Tayler Lewis and Mr F. McPartlan. *Mercury*, 2 June 1859.

LITTLE, J., 1833: Account of a journey from Macquarie Harbour to the Huon. *Hobart Town Chron.*, 26 Mar. 1833.

MARRIOTT, R., 1908: Report on track connecting Webster's Track with Great Western Railway Track. Department of Lands and Surveys: report for the year ended 30th June 1908. *Parl. Tasm. J.* 1908, rep. 13.

MARSDEN, E.A., 1898: Unpublished report regarding the construction of the track from Frodshams Pass to Bathurst Harbour. Lands and Survey Department, Hobart, Tasmania. LSD 6/194/849c, Archives Office of Tasmania.

MARSDEN-SMEDLEY, J.B., 1990: The ecology of moorland-copse boundaries in southwest Tasmanian oligotrophic environments. Unpubl. Hons thesis, Dep. Plant Sci., Univ. Tasm.

MARSDEN-SMEDLEY, J.B., 1993a: Fuel characteristics and fire behaviour in Tasmanian buttongrass moorlands. Parks & Wildl. Serv., Dep. Environ. Land Manage., Hobart, Tasmania.

MARSDEN-SMEDLEY, J.B. 1993b: Orange-bellied parrot recovery plan: operational prescriptions for habitat management burns. Unpubl. rep. Parks & Wildl. Serv., Dep. Environ. Land Manage., Hobart, Tasmania.

MARSDEN-SMEDLEY, J.B., 1997: Fire and fuel in Tasmanian buttongrass moorlands: regimes, characteristics, behaviour and management. Unpubl. PhD thesis, Dep. Geogr. Environ. Stud., Univ. Tasm., Hobart, Tasmania.

MARSDEN-SMEDLEY, J.B., CATCHPOLE, W.R. & PYRKE, A., 1998: Unbounded burning in Tasmanian buttongrass moorlands: fire behaviour modelling and operational prescriptions. Rep. Parks Wildl. Serv., For. Tasm. and Tasm. Fire Serv.

MCRAE, M.D., 1960: Port Davey and the South-west. *Pap. Proc. Tasm. Hist. Res. Assoc.* 8: 46–50.

MCSHANE, I., 1982: T.B. Moore — a bushman of learning. Unpubl. Hons thesis, Univ. Tasm.

MEREDITH, G.C., 1876: *JOURNAL OF A PROSPECTING TRIP TO WESTERN TASMANIA.* AOT NS718/1.

MEREDITH, G.C., 1898: *JOURNAL OF A PROSPECTING TRIP TO SOUTHWESTERN TASMANIA.* AOT NS718/9.

MOORE, T.B., 1887: Account of a trip to Frenchmans Cap in 1887. Reprinted in 1970. *Skyline* 20: 5–9.

MUTCH, R.W., 1994: Fighting fire with prescribed fire: a return to ecosystem health. *J. For.* 92: 31–33.

PARKS AND WILDLIFE SERVICE, 1997: *TASMANIAN WILDERNESS WORLD HERITAGE AREA DRAFT MANAGEMENT PLAN.* Parks and Wildlife Service, Department of Environment and Land Management, Hobart, Tasmania.

PEMBERTON, M., 1988: Soil erosion between Birchs Inlet and Elliott Bay, southwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 122: 109–114.

PEMBERTON, M., 1989: *Land systems of Tasmania region 7 — Southwest.* Department of Agriculture, Hobart, Tasmania.

PEMBERTON, M. & CULLEN, P., 1995: Impacts of fire on soils in Tasmania. *In* Blanks, A.B. (Ed.): *BUSHFIRE '95. Proceedings of the Australian Bushfire Conference. 27–30 Sep. 1995, Hobart, Tasmania.* Jointly published by Parks and Wildlife Service, Forestry Tasmania and Tasmania Fire Service.

PERRIN, G.S., 1887: Wood and forests of Tasmania: report of the Conservator of Forests, 1886–7. *Parl. Tasm. J.* 1887, report 59.

PERRIN, G.S., 1898: Forests of Tasmania: their conservation and future management. *Parl. Tasm. J.* 1898, report 48.

PETERSON, M., 1990: *DISTRIBUTION AND CONSERVATION OF HUON PINE.* Forestry Commission, Hobart, Tasmania.

PHILP, J.E., 1937: Unpublished manuscript: Where tracks are made. NS 21/22/1, Archives Office of Tasmania.

PIGUENIT, W.C., 1892: Among the Western Highlands of Tasmania. Report of the Fourth Meeting of the Australasian Association for the Advancement of Science, 1892, Hobart, Tasmania. *Trans. Australas. Assoc. Adv. Sci.* Government Printer, Tasmania.

PLOMLEY, N.J.B., 1966: *FRIENDLY MISSION: THE TASMANIAN JOURNALS AND PAPERS OF GEORGE AUGUSTUS ROBINSON 1829-1834.* Tasmanian Historical Research Association, Hobart, Tasmania.

PLOMLEY, N.J.B., 1991: *JORGEN JORGENSON AND THE ABORIGINES OF VAN DIEMEN'S LAND.* Blubberhead Press, Hobart, Tasmania, Australia.

ROBERTSON, D.I. & DUNCAN, F., 1991: *DISTRIBUTION AND CONSERVATION OF DECIDUOUS BEECH.* Forestry Commission Tasmania and Department of Parks, Wildlife and Heritage, Hobart, Tasmania.

ROTH, H.L., 1899: *THE ABORIGINES OF TASMANIA.* Fullers Bookshop, Hobart, Tasmania.

SCHULLERY, P., 1989: The fires and fire policy. The drama of the 1988 Yellowstone fires generated a review of national policy. *BioScience* 39: 686-694.

SCOTT, J.R., 1871: Arthur Plains and Port Davey. *Mercury,* 5 Apr. 1871.

SCOTT, J.R., 1875: Port Davey in 1875. *Pap. R. Soc. Tasm.*

SHARLAND, W.S., 1861: Rough notes of a journal of expedition to the westward in 1832. Survey Office Reports, *Legislative Council Journal* vol. VI, part 1, rep. 16, Hobart, Tasmania.

STATE EMERGENCY SERVICE, 1990: *History of emergency events issue* 1. July 1990. State Emergency Service, Hobart, Tasmania.

STOCKTON, J., 1982: Fires by the seaside: historic vegetation changes in northwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 116: 53–66.

THIRKELL, R.A.C., 1908: Report on track from Mt Arrowsmith to Gordon River. Department of Lands and Surveys: report for the year ended 30th June 1908. *Parl. Tasm. J.* 1908, rep. 13.

THOMAS, I., 1991: The Holocene archaeology and palaeoecology of Northeastern Tasmania, Australia. Unpubl. PhD thesis, Univ. Tasm.

THOMAS, I., 1993a: Late Pleistocene environments and Aboriginal settlement patterns in Tasmania. *Aust. Archaeol.* 36: 1–11.

THOMAS, I., 1993b: The Central Highlands. *In* Smith, S.J. & Banks, M.R. (Eds): *TASMANIAN WILDERNESS — WORLD HERITAGE VALUES.* Royal Society of Tasmania, Hobart, Tasmania.

THOMAS, I., 1995: Where has all the forest gone: new pollen evidence from Melaleuca Inlet in SW Tasmania. *In* Dixon, G. & Aitkin, D. (Eds): *Monash Univ. Publ. Geogr.* 45: 295–301.

THOMAS, I. & HOPE, G., 1994: An example of Holocene vegetation stability from Camerons Lagoon, a near treeline site on the Central Plateau, Tasmania. *Aust. J. Ecol.* 19: 150–158.

THWAITES, J.B., 1934: Frenchman's Cap. *Tasm. Tramp* 3: 5-11.

TULLY, W.A., 1859: The western country. *Mercury,* 26 Apr. 1859.

TWELVETREES, W.H., 1906: Unpublished report on the Cox Bight Tin field. AC 19. Archives Office of Tasmania.

TWELVETREES, W.H., 1908: Report by Mr. W. H. Twelvetrees, Government Geologist. Department of Lands and Surveys: report for the year ended 30th June 1908. *Parl. Tasm. J.* 1908, rep. 13.

TWELVETREES, W.H. 1909: Western exploration: report on journey to the Gordon River by Mr. W. H. Twelvetrees, Government Geologist. Department of Lands and Surveys: report for the year ended 30th June 1909. *Parl. Tasm. J.* 1909, rep. 21.

TWELVETREES, W.H., 1915: *Annual report of the Government Geologist.* Department of Mines, Hobart, Tasmania.

TYLER, W.H. & HARPER, W.T., 1906: Cox's Bight. *Mercury,* 19 Apr. 1906.

WALKER, J.B., 1887: Walk to the west. *In* Stoddart, M. (Ed.): *JOURNAL OF A TRIP TO TASMANIA'S WEST COAST, 17 FEBRUARY TO 5 MARCH 1887.* Royal Society of Tasmania.

WALLACE, W.H., 1901: Report of the Secretary for Mines for 1900-1901. *Parl. Tasm. J.* 1901, rep. 4.

WARD, L.K., 1908: Report by L. K. Ward, Assistant Government Geologist. Department of Lands and Surveys: report for the year ended 30th June 1908. *Parl. Tasm. J.* 1908, rep. 13.

WARD, L.K. 1909: Report by L. K. Ward, Assistant Government Geologist. Department of Lands and Surveys: report for the year ended 30th June 1909. *Parl. Tasm. J.* 1909, rep. 21.

WARREN, R., 1936: Diary of two wretched females on a trip to Frenchman's Cap. *Tasmanian Tramp* 5: 44–48.

(accepted 11 November 1997)

RESPONSES TO WATERLOGGING AND FROST RELATED TO THE TOPOGRAPHIC SEQUENCES OF EUCALYPT SPECIES AT THREE SITES IN CENTRAL TASMANIA

by J.B. Kirkpatrick and N. Gibson

(with four tables)

KIRKPATRICK, J.B. & GIBSON, N., 1998 (31:xii): Responses to waterlogging and frost related to the topographic sequences of eucalypt species at three sites in central Tasmania. *Pap. Proc. R. Soc. Tasm.* 132: 31–34. ISSN 0080–4703. School of Geography and Environmental Studies, University of Tasmania, GPO Box 252-78, Hobart, Tasmania, Australia 7001 (JBK); Wildlife Research Centre, CALM, PO Box 51, Wanneroo, WA, Australia 6065 (NG, formerly University of Tasmania).

The boundaries between the eucalypt species typical of flats and hollows and those typical of slopes have been commonly attributed to variable waterlogging and/or frost resistance. Seedlings from three pairs of eucalypt species from the flats and slopes at three altitudes in central Tasmania (*Eucalyptus ovata, E. rubida*, 500 m; *E. rodwayi, E. pauciflora*, 800 m; *E. gunnii, E. coccifera*, 1000 m) were grown in a glasshouse experiment to test the interactive effects of species, waterlogging and fertiliser application on growth, frost resistance and frost recovery. The flats species largely proved more resistant to waterlogging, especially when fertilised, and less resistant to frost than the slopes species. Thus, it seems likely that the boundaries between the pairs of species are caused by relative frost resistance not waterlogging resistance.

Key Words: distribution, *Eucalyptus*, frost, nutrients, Tasmania, topography, waterlogging.

INTRODUCTION

Valley flats and hollows with few or no trees are a frequent feature of the natural landscape of southeastern Australia. In most such places, the eucalypt species occupying the flats or hollows and/or their margins differ from those occupying the adjacent slopes. Examples of the phenomenon include *Eucalyptus pauciflora* (slopes) and *E. stellulata* (flats) in the high mountains of southeastern Australia (Costin 1954), and *E. viminalis* (slopes) and *E. ovata* (flats) in southern Victoria and much of Tasmania (e.g. Ladiges & Kelso 1977).

In most but not all (Parsons 1967) investigations of the relative waterlogging tolerance of *Eucalyptus* species, those that occur in the more waterlogged environments exhibit a lesser growth check upon the imposition of experimental inundation than those that occur in freely drained environments (e.g. Ladiges & Kelso 1977, Blake & Reid 1981, Guest 1982, Davidson 1985). An alternative explanation for the patterning of eucalypt species at the base of mountain slopes, at least in montane and subalpine environments, is relative frost resistance. For example, Davidson & Reid (1987) found that *E. gunnii*, the species occupying the base of a frost hollow in the Snug Tiers, Tasmania, was less damaged by growing-season frost than the eucalypt species upslope. They also demonstrated interactive effects between frost and waterlogging tolerance, with *Monocalyptus* species having less ability to harden under waterlogging than *Symphyomyrtus* species.

In Tasmania, the eucalypt species that occupy the most waterlogged ground all belong to the subgenus *Symphyomyrtus*. The most widespread of these species is *E. ovata*, which occurs on soils of widely varying texture and fertility in the lowlands. *E. perriniana* and *E. cordata* are lowland species of waterlogged ground with much more restricted distributions (Williams & Potts 1996). *E. rodwayi* is the species of waterlogged ground in the montane zone. This species has a wide edaphic range. At high altitude, the more fertile of the waterlogged soils are occupied by *E. gunnii*, while *E. subcrenulata* is found on the nutrient-poorer sites. A wide variety of other *Symphyomyrtus* and *Monocalyptus* species occur upslope of the waterlogged ground. Detailed maps of such distribution patterns are given in Fensham & Kirkpatrick (1992) for areas containing flats occupied by *E. ovata* (Bothwell), *E. rodwayi* (Shannon) and *E. gunnii* (Sandbank) at low, montane and subalpine altitudes in central Tasmania. At Bothwell, *E. ovata* was replaced by *E. viminalis* (*Symphyomyrtus*) on the dolerite slope, and by *E. rubida* (*Symphyomyrtus*) on the mudstone slope of an alluvium-filled valley at 500 m. At Shannon (800 m), *E. rodwayi* was replaced by *E. pauciflora* (*Monocalyptus*) on the slopes and, at Sandbank (1000 m), *E. gunnii* was replaced by *E. coccifera* (*Monocalyptus*).

The present paper reports an experiment designed to test the growth and unhardened frost, waterlogging and fertiliser application responses of *E. ovata, E. rodwayi* and *E. gunnii* and of one upslope neighbour of each of these, i.e. *E. rubida, E. pauciflora* and *E. coccifera*, at the sites studied by Fensham & Kirkpatrick (1992). Our implicit hypothesis was that the species of the flats would be more tolerant of both growing-season frost and waterlogging than their upslope neighbours.

METHODS

Seed was obtained from at least five trees of each species as close as possible to one of the Bothwell, Shannon and Sandbank sites of Fensham & Kirkpatrick (1992). Thus, seeds for *E. ovata* and *E. rubida* were obtained from near Bothwell, for *E. pauciflora* and *E. rodwayi* from near Shannon, and for *E. coccifera* and *E. gunnii* from near Sandbank. The seed for each species was mixed before germination. The germinants were transplanted into 170 mm diameter tubular plastic pots filled with a mixture of grey sand and peat. Ten pots of each species were allocated to each of the factorial combinations of fertiliser application and waterlogging. The pots were totally randomised within a heated glasshouse. The fertiliser treatment consisted of the application of 0.32 g of Aquasol (N:P:K, 23:4:18) at the recommended

dilution (200 mL water) per pot once a week. The waterlogging treatment was imposed from one month onwards and consisted of flooding to the surface of the soil. The frosting of all seedlings was undertaken after four months in a controlled temperature chamber. The roots of all seedlings were protected against frost by *Sphagnum* packing. The pots were randomised within the chamber to avoid results being influenced by any internal temperature gradients. Temperatures were lowered 5°C per hour until they attained –5°C. This temperature was maintained for two hours, then the seedlings were returned to the glasshouse. The methods of Ashton (1958) were used to measure leaf damage and recovery. These methods express leaf damage as a mean proportion and recovery as the proportion of new shoots from leaf axils. Seedling height, number of leaf pairs and number of branches were measured at four months before frosting began. The data for these five variables was analysed using ANOVA with appropriate transformations (Sokal & Rohlf 1981). The two-tailed Student's t-test was used to test the significance of different levels of frost damage and height between species. A probability level of 0.05 was adopted for the rejection of null hypotheses.

RESULTS

There was a significant species by waterlogging by fertiliser application interaction for the three growth variables (tables 1, 2). The effect of waterlogging on the relative height growth of species varied with fertilisation. In the unfertilised pots, the order of species from that most to that least affected by waterlogging was *E. gunnii*, *E. rubida*, *E. pauciflora*, *E. coccifera*, *E. rodwayi*, *E. ovata*. In the fertilised pots the equivalent order was *E. pauciflora*, *E. rubida*, *E. coccifera*, *E. rodwayi*, *E. gunnii*, *E. ovata*. Waterlogging increased the height growth of *E. ovata* in fertilised pots, while only decreasing it marginally in unfertilised pots. In contrast, its upslope neighbour, *E. rubida*, attained less than 40% of its unwaterlogged heights in both fertilised and unfertilised pots, suffering proportionately more in the fertilised condition. Fertiliser application did not affect the reduction of height caused by waterlogging of *E. rodwayi*, which was to approximately 65% of the unwaterlogged plants. Its upslope neighbour, *E. pauciflora*, suffered more from waterlogging in the fertilised pots, with a reduction to 21% of its unwaterlogged height, than in the unfertilised pots, where the equivalent figure was 46%. *E. gunnii* attained only 35% of its unwaterlogged height in unfertilised pots, while attaining 70% in fertilised pots. Its upslope neighbour, *E. coccifera*, was reduced in height by approximately half in both fertilised and unfertilised pots, with a slightly greater reduction in the former. Thus, all the species of the slopes suffered proportionately more from waterlogging in fertilised pots, while all the species of the flats showed the reverse pattern or no change. In the cases of *E. ovata* versus *E. rubida* and *E. rodwayi* versus *E. pauciflora* there was a significant difference ($P < 0.001$) in height within the fertilised and waterlogged treatment, but not within the unfertilised and waterlogged treatment ($P > 0.05$). In the case of *E. gunnii* versus *E. coccifera*, the significant difference pertained to the unfertilised and waterlogged treatment ($P < 0.001$), not the fertilised and waterlogged treatment ($P > 0.05$).

The number of leaves exhibited similar patterns of response to seedling height, except that *E. pauciflora*, the slopes species, performed marginally better in waterlogged, unfertilised conditions than *E. rodwayi*, and this latter species had a proportionately slightly greater reduction in growth in fertilised, waterlogged conditions than in unfertilised, waterlogged conditions (table 2).

Branching was rare in unfertilised pots, especially those that were waterlogged, although *E. ovata* increased its mean number of branches with waterlogging. In fertilised pots branching was more prolific, especially when the pots were not waterlogged, with *E. ovata* again being an exception by increasing its mean branch number with waterlogging (table 2). In the fertilised, waterlogged treatment, the three flats species maintained high numbers of branches, while branches were absent or rare on the seedlings of the slopes species (table 2).

Waterlogging significantly decreased frost damage and recovery, and fertiliser application increased them (table 1). There were no significant interactive effects (table 3). The order from the most frost-damaged to the least frost-damaged species was *E. gunnii*, *E. ovata*, *E. rodwayi*, *E. coccifera*, *E. rubida*, *E. pauciflora* (table 3). However, the order of species differed markedly between treatments (table 4). For example, *E. gunnii* was little damaged in the waterlogging–no fertiliser treatment, while being heavily damaged in all others (table 4). While the three species of the flats were all more damaged than the three species of the slopes, only the comparison between *E. ovata* and *E. rubida* was significant among the three pairs (table 3). *E. rubida* was also significantly less frost-damaged than *E. rodwayi* and *E. gunnii*, and *E. pauciflora* was significantly less damaged than *E. ovata* and *E. gunnii* (table 3). There was no significant species effect for recovery (table 1). There were no interactive effects for the damage and recovery variables (table 1).

DISCUSSION

The results of our experiment support relative resistance to waterlogging but not to frost, as a cause of the local distribution patterns of the three pairs of species, given that the species of the slopes, where frosts are less frequent and intense than on the flats (Fensham & Kirkpatrick 1992), were less damaged by frost in an unhardened state than those of the flats. It is likely that major frost damage in the field occurs in the growing season (Davidson & Reid 1987), as well as in the winter months. In this respect, it is interesting to note that the differences in frost resistance between *E. rodwayi*, *E. gunnii* and *E. ovata* became less apparent after hardening in other experiments similar to those reported herein (Kirkpatrick & Gibson, in press), as did the differences reported by Davidson & Reid (1987). In another experiment, with only mildly hardened seedlings and the same frosting procedures, Kirkpatrick & Gibson (in press) found *E. rodwayi* to be significantly less damaged than *E. ovata* and *E. gunnii*, a result consistent with their reciprocal planting experiments. This result agrees with the order of resistance found in the present experiment, in which the faster growing seedlings sustained more damage than the slower growing seedlings, with Pearsons product moment correlations between arcsin damage and all of height, leaf number and branch number being significant at $P < 0.001$. This result suggests that hardening through lack of nutrients and/or waterlogging can ameliorate the impacts of frosting. Hardening induced by waterlogging, in the absence of fertiliser application, reduced or reversed the contrast in

TABLE 1
Results of the analysis of variance for the waterlogging and fertiliser application experiment with six eucalypt species

Treatment	Height (log)	Leaf no. (log)	Branches (log)	Damage (arc sin)	Recovery
Species (S)	***	***	***	*	NS
Waterlogging (W)	***	***	***	***	*
Fertilizer (F)	***	***	***	***	*
S x W	***	***	***	NS	NS
S x F	***	***	***	NS	NS
W x F	NS	NS	***	NS	NS
S x W x F	***	***	**	NS	NS

*** = P < 0.001, ** = P <0.01, * = P < 0.05, NS = P > 0.05.

TABLE 2
Means and standard errors ( ) in the three growth variables for the six species in the fertiliser application and waterlogging treatments*

Species	F-W-	F-W+	F+W-	F+W+
	Seedling height (cm)			
E. ovata	10.3 (0.9)	8.0 (0.8)	23.1 (1.5)	26.4 (1.6)
E. rubida	16.1 (1.8)	6.5 (0.7)	32.2 (2.1)	9.2 (1.0)
E. rodwayi	7.1 (1.1)	4.6 (0.6)	26.7 (1.2)	17.3 (1.7)
E. pauciflora	7.2 (0.7)	3.3 (0.3)	22.3 (2.3)	4.6 (0.3)
E. gunnii	7.9 (1.0)	2.8 (0.3)	17.8 (1.9)	12.4 (2.3)
E. coccifera	13.1 (1.6)	6.6 (0.7)	19.3 (1.6)	8.6 (1.7)
	Number of leaves			
	F-W-	F-W+	F+W-	F+W+
E. ovata	10.3 (0.2)	8.5 (0.2)	27.5 (0.8)	36.3 (1.1)
E. rubida	11.4 (0.1)	5.2 (0.2)	23.5 (0.7)	7.6 (0.2)
E. rodwayi	11.6 (0.4)	7.5 (0.2)	45.8 (1.4)	28.4 (1.0)
E. pauciflora	7.3 (0.1)	5.0 (0.1)	19.9 (0.7)	5.8 (0.2)
E. gunnii	13.5 (0.4)	5.3 (0.2)	41.6 (1.8)	32.4 (1.8)
E. coccifera	12.6 (0.4)	5.9 (0.1)	37.0 (1.2)	9.2 (0.4)
	Number of branches			
	F-W-	F-W+	F+W-	F+W+
E. ovata	0.1 (0.0)	0.3 (0.0)	3.3 (0.1)	4.8 (0.2)
E. rubida	0.0 (0.0)	0.0 (0.0)	2.2 (0.1)	0.0 (0.0)
E. rodwayi	0.3 (0.0)	0.0 (0.0)	8.1 (0.2)	5.0 (0.3)
E. pauciflora	0.0 (0.0)	0.0 (0.0)	2.3 (0.1)	0.0 (0.0)
E. gunnii	0.0 (0.0)	0.0 (0.0)	5.2 (0.3)	4.2 (0.3)
E. coccifera	0.9 (0.1)	0.0 (0.0)	7.6 (0.2)	1.0 (0.1)

* F+ = fertilised, F- = fertilised, W+ = waterlogged, W- = not waterlogged.

frost resistance between *E. gunnii* and *E. coccifera*, and *E. rodwayi* and *E. pauciflora*, while accentuating the difference between *E. ovata* and *E. rubida* (table 4). Thus, on the more frost-prone sites, there appears to be little difference in frost resistance between slopes and flats species in conditions that most closely relate to nature, whereas, on the least frost-prone site, the slopes species is markedly more frost-resistant than the flats species in these conditions. These results further reinforce the conclusion that the relative distributions of the three pairs of species at the sites are not a product of relative frost resistance.

The failure of *E. gunnii* to resist waterlogging in nutrient-poor conditions and its success in nutrient-rich conditions, reflect a narrower edaphic range than the other two flats species. The success of *E. ovata* in resisting waterlogging is consistent with earlier work comparing this species with those of better-drained ground (Ladiges & Kelso 1977, Guest 1982). The outstanding growth of *E. ovata* in the waterlogged and fertilised treatment (table 2) may relate to its possession of aerenchymatous roots at the start of the waterlogging treatment, thereby being able to take advantage of the accumulation of nutrients, in contrast to those species without such an initial state (N.J. Davidson, pers. comm.).

Davidson & Reid (1987) reported that *E. coccifera* was more damaged than *E. gunnii* in a growing season frost of −5.5°C at Snug Tier, Tasmania, whereas we found no significant difference in frost response. The inconsistency

TABLE 3
Mean frost damage index† by species (FDI), with significant differences‡

Species	FDI	G	O	RO	C	RU	P
E. gunnii (G)	0.70		ns	ns	ns	*	**
E. ovata (O)	0.66	ns		ns	ns	*	**
E. rodwayi (RO)	0.66	ns	ns		ns	*	ns
E. coccifera (C)	0.54	ns	ns	ns		ns	ns
E. rubida (RU)	0.32	*	*	*	ns		ns
E. pauciflora (P)	0.28	**	**	ns	ns	ns	

† Back-transformed from an arcsin transformation.
‡ ns = P < 0.05, * = P < 0.05, ** = P < 0.01, Two-tailed Students t-test.

TABLE 4
Mean frost damage index* by species and treatment†

Species	W+F+	W+F-	W-F+	W-F-
E. gunnii (G)	0.74	0.12	0.97	0.76
E. ovata (O)	0.56	0.66	0.90	0.52
E. rodwayi (RO)	0.72	0.19	0.43	0.71
E. coccifera (C)	0.41	0.38	0.78	0.61
E. rubida (RU)	0.26	0.02	0.74	0.55
E. pauciflora (P)	0.21	0.10	0.61	0.29

* Back-transformed from an arcsin transformation.
† F+ = fertilised, F- = not fertilised, W+ = waterlogged, W- = not waterlogged.

between our results and theirs may relate to the very different conditions that preceded and postdated frosting, or to the known geographic variation in frost resistance within both taxa (Potts 1985, Gilfedder 1988).

CONCLUSIONS

The role of frost in vegetation patterning may not be great in Tasmania. Here frost-caused defoliation appears to be relatively common (Breton 1846, Calder 1850, Jackson 1973, Davidson & Reid 1987, Gilfedder 1988, Cullen & Kirkpatrick 1988, Fensham & Kirkpatrick 1992), but there is only circumstantial evidence of the displacement of species from sites as a result of such defoliation, and this evidence relates to areas that were subject not only to severe frost but also to the early stages of a history of highly intense stock-grazing. In the cases of all the twentieth-century records of frost-induced defoliation, seedling regeneration or recovery through epicormic growth has maintained the damaged species on the site.

Our results cannot be taken as conclusive proof that relative waterlogging resistance is the prime cause of the boundaries between the flats and the slopes species. While the results do not invalidate this hypothesis, other mechanisms, such as relative ability to compete with a dense grass sward in the seedling stage and different interactions with the rest of the biota (Fensham & Kirkpatrick 1992) could be important.

ACKNOWLEDGEMENTS

This study was supported by a grant from the Australian Research Council. We are grateful to Kristine Williams, Neil Davidson and Chris Harwood for their comments on an earlier draft of this paper.

REFERENCES

Ashton, D.H., 1958: Ecology of *Eucalyptus regnans* F. Muell: the species and its frost resistance. *Aust. J. Bot.* 6: 154–176.

Blake, T.J. & Reid, D.M., 1981: Ethylene, water relations and tolerance to waterlogging of three *Eucalyptus* species. *Aust. J. Plant. Physiol.* 8: 497–505.

Breton, W.H., 1846: Excursion to the Western Range, Tasmania. *Tasm. J.* II: 121–140.

Calder, J.E., 1850: Some account of the country between Hamilton and Frenchman's Cap. *Hobart Town Courier* Saturday 21 September 1850.

Costin, A.B., 1954: *A STUDY OF THE ECOSYSTEMS OF THE MONARO REGION OF NEW SOUTH WALES.* Government Printer, Sydney.

Cullen, P.C. & Kirkpatrick, J.B., 1988: The ecology of *Athrotaxis* D. Don (Taxodiaceae) II. The distributions and ecological differentiation of *A. cupressoides* and *A. selaginoides. Aust. J. Bot.* 36: 561–573.

Davidson, N.J., 1985: Ecophysiological studies of factors determining the distribution of subalpine eucalypts at Snug Plains, southern Tasmania. Unpubl. PhD thesis, Univ. Tasm.

Davidson, N.J. & Reid, J.B., 1987: The influence of hardening and waterlogging on the frost resistance of subalpine eucalypts. *Aust. J. Bot.* 35: 91–101.

Fensham, R.J. & Kirkpatrick, J.B., 1992: The eucalypt forest–grassland/grassy woodland boundary in central Tasmania. *Aust. J. Bot.* 40: 123–138.

Gilfedder, L., 1988: Factors influencing the maintenance of an inverted *Eucalyptus coccifera* treeline on the Mt. Wellington Plateau, Tasmania. *Aust. J. Ecol.* 13: 495–503.

Guest, S.A., 1982: The adaptive significance of seedling characteristics of *Eucalyptus ovata* Labill. and *E. brookerana* A.M. Gray. Unpubl. MSc thesis, Univ. Melbourne.

Jackson, W.D., 1973: Vegetation of the Central Plateau. *In* Banks, M.R. (Ed.): *THE LAKE COUNTRY OF TASMANIA.* Royal Society of Tasmania, Hobart: 61–85.

Kirkpatrick, J.B. & Gibson, N., in press. Towards an explanation of the altitudinal distributions of three species of *Eucalyptus* in central Tasmania. *Aust. J. Ecol.*

Ladiges, P. & Kelso, A., 1977: The comparative effects of waterlogging on two populations of *Eucalyptus viminalis* Labill. and one population of *E. ovata* Labill. *Aust. J. Bot.* 25: 159–169.

Parsons, R.F., 1967: Effects of waterlogging and salinity on growth and distribution of three mallee species of *Eucalyptus. Aust. J. Bot.* 16: 101–108.

Potts, B.M., 1985: Variation in the *Eucalyptus E. gunnii-archeri* complex. III. Reciprocal transplant trials. *Aust. J. Bot.* 33: 687–704.

Sokal, R.R. & Rohlf, F.J., 1981: *BIOMETRY.* 2nd edn. Freeman, San Francisco.

Williams, K. J. & Potts, B.M., 1996: The natural distribution of *Eucalyptus* species in Tasmania. *Tasforests* 8: 39–165.

(accepted 5 May 1998)

HOLOCENE LANDSCAPE INSTABILITY IN THE DAZZLER RANGE, NORTHERN TASMANIA

by Kevin Kiernan

(with two text-figures)

KIERNAN, KEVIN, 1998 (31:xii): Holocene landscape instability in the Dazzler Range, northern Tasmania. *Pap. Proc. R. Soc. Tasm.* 132: 35–40. ISSN 0080–4703. Forest Practices Board, 30 Patrick Street, Hobart, Tasmania, Australia.

At least 5 m of poorly consolidated Quaternary sediments have accumulated since the mid Holocene in the lower reaches of stream channels that drain the flanks of the Dazzler Range. Radiocarbon assay of charcoal and wood fragments contained in the sediments indicate deposition during the mid to late Holocene 5.2–1.8 ka. Coarse gravels in the earliest deposits are believed to have been recycled from relict periglacial gravels in response to increased runoff and channel instability, brought about by neoglacial cooling coupled with changes in vegetation structure and associated fire frequency. The thickness of the sediments and the presence of large logs in the sediments along the lower reaches of Branchs Creek suggest at least one geomorphic event of high magnitude. Significant aggradation of finer calibre sediments has continued during the last two millenia. Since European settlement, deep gulleys have formed in the lower reaches of alluvial fans that flank the range, in response to land clearing for agriculture and the artificial straightening of stream channels. The earlier history of slope instability and sediment aggradation, even under natural conditions, highlights the need for careful land management.
Key Words: Tasmania Dazzler Range, Holocene, radiocarbon dating, fluvial geomorphology, periglaciation, slope stability, channel stability, land management.

INTRODUCTION

Aggradation in the form of valley fills and slope deposits dated to the mid to late Holocene has been reported from several parts of Tasmania. Some researchers have suggested there to have been a period of relative aridity in the mid Holocene and/or increased burning by Aborigines, in order to explain the catchment destabilisation necessary to cause aggradation of the magnitudes reported (Goede 1973, Davies 1974). Evidence has recently emerged that considerable mid to late Holocene aggradation has also occurred along the lower reaches of two of the principal streams that drain the Dazzler Range in central northern Tasmania. This paper addresses the nature and likely origin of these sediments, and considers their implications for land management in this area.

The Dazzler Range comprises a small system of hills and ridges that stretches NNW–SSE, commencing a few kilometres from the northern coastline of Tasmania and extending inland for ~ 20 km (fig. 1). The range is drained by streams that discharge eastwards into the lower Tamar River estuary, northwards into Bass Strait, and westwards into Port Sorell. It rises to just over 500 m altitude and comprises mainly sandstones, slates and phyllites of the Proterozoic Badger Head Group, with sands and gravels of Tertiary age flanking the range (Gee & Legge 1970).

The climate of the Dazzler Range is moderated by its close proximity to Bass Strait, although conditions are likely to have been more arid during the low sea level stands of the Pleistocene, when much of Bass Strait was exposed as dry land, and the setting of the Dazzler Range was more continental than at present. The nearest stations from which present-day climatic data are available are Devonport East (46 m altitude), 23 km west of the Dazzler Range, and Low Head Lighthouse (28 m altitude), 10 km to the northeast of the range. Mean annual maximum and minimum temperatures are respectively 16.8° and 8.1°C at Devonport and 16.1° and 9.4°C at Low Head. Annual rainfall totals are significantly higher at Devonport East (895.7 mm) than at Low Head (680.7 mm). However, the highest daily recorded rainfall is from Low Head (113.0 mm versus 86.6 mm at Devonport East).

The northernmost extremity of the Dazzler Range lies in the Asbestos Range National Park, but further inland most of the range has the status of State forest. Some freehold land is also present. Logging of some of the slopes and forest plantation development has occurred in recent decades. Clearing for agricultural purposes has extended onto some lower slopes since the earliest days of European settlement.

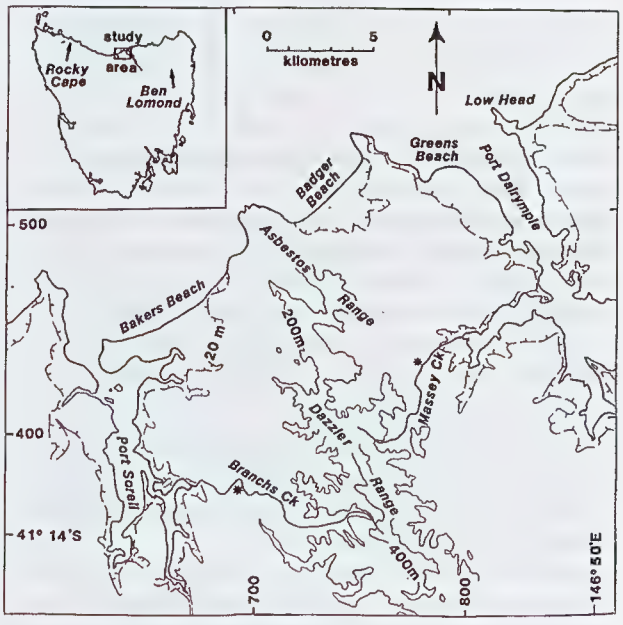


FIG. 1 — Location of the study area.

PREVIOUS RESEARCH IN THE DAZZLER RANGE AREA

The catchments of the principal streams that drain the Dazzler Range remain forested in all but their lowermost reaches. The channels in this area appear to be stable, and deep natural sections that allow examination of the Quaternary stratigraphy are rare. However, the stratigraphy of some alluvial fans that flank the range is locally revealed in erosion gullies formed in pasture areas. The effect is most pronounced where channelisation of water flowing through formerly swampy ground has led to a significant increase in the erosive capacity of flows through the channel relative to that upstream. In such situations, massive gully erosion is common, if sediment supply from upstream is less than the erosive capacity of the flow downstream. Channel adjustment is achieved by bed and gully-head erosion and scour (Bird 1985, O'Loughlin 1991).

Given the relatively high altitude attained by the Dazzler Range and the presence of periglacial sediments close to sea level at Rocky Cape ~100 km to the WNW (Colhoun 1977), it seems reasonable to assume that periglacial activity is also likely to have played a significant role in landscape evolution here. However, there is no evidence of periglacial processes being active to any significant degree today. If the standard lapse rate of 0.6°C/100 m (Cole 1975) is assumed, then the temperature data from Devonport East and Low Head Lighthouse suggest present-day mean annual maximum and minimum temperatures of ~13° and ~8°C atop the Dazzler Range. However, assuming a mean annual temperature (MAT) ~6.5°C lower than now during the Last Glacial Maximum (LGM) (Colhoun *et al.* 1996), the Dazzler Range is likely to have been a strongly periglacial environment during the Glacial Climatic Stages of the Pleistocene. By analogy with slope deposits at Rocky Cape, where Colhoun (1977) has obtained five dates of 24.1–33.2ka for organic materials in alluvial fan deposits, some of the diamictons on the slopes of the Dazzler Range and some of the alluvial fans probably date from the LGM and are the product of periglacial activity.

Although the geomorphology of the Dazzler Range has been little studied, the coastal geomorphology and sediments at the northern end of the range have received some attention. A well-developed series of parallel sand beach ridges of Holocene age occurs at Bakers Beach on the western side of the range (Davies 1972). Chick (unpubl. data) has obtained dates of 31 960 +3400/–2380 yr BP (Gak 5620) for wave-worn peat masses derived from below low tide level at Badger Beach on the eastern side of the Dazzler Range (Colhoun 1985). He also obtained results of 7850 ± 140 yr BP (Gak 5621) for a peat bed at mid tide level and 8020 ± 140 yr BP (Gak 5622) for a peat bed at high tide level. Organic clay from a podsol beneath a dune formed on beach sands at Badger Beach (694471) gave a radiocarbon age of 15 900 ± 510 yr BP (Gak 5619). Fish & Yaxley (1966: 171) have reported a radiocarbon age of 7380 ± 100 yr BP (NZ1219) for a portion of tree stump in an intertidal peat bed at Badger Beach (740507). These dates reflect exposure of the present sea floor during the Last Glacial Stage and its subsequent inundation during the Holocene transgression.

A little further east, Thom *et al.* (1981) have reported four radiocarbon dates from shell hash samples from Greens Beach at the mouth of the Tamar estuary: 6085 ± 90 yr BP (SUA 1297); 38 765 +2700/–2015 yr BP (SUA 1298); 8005 ± 90 yr BP (SUA 1299); and 3770 ± 70 yr BP (SUA 1300). However, interpretation of shell hash dates is complicated by the fact that interglacial marine sediments were eroded and later redeposited with more recent material as Holocene marine transgression occurred (Colhoun 1986).

The height of the Last Interglacial shoreline in this area is unresolved. However, in view of evidence for 20–30 m of uplift around parts of the Tasmanian coastline since the Last Interglacial Stage (Murray-Wallace & Goede 1995), coastal processes are also likely to have played a role in the evolution of some lower slopes, assuming comparable tectonic activity in the Dazzler Range area. Uplift of this order would imply marine inundation into the lowermost reaches of some valleys that drain westwards and eastwards from the Dazzler Range.

BRANCHS CREEK SEDIMENTS

Branchs Creek rises from ~500 m altitude and flows westwards into the South East Arm of Port Sorell, the estuary of the Rubicon River and the Franklin Rivulet. An alluvial fan with its apex at ~30 m altitude has formed 2 km from tidewater, at the break of slope at the foot of the range at ~690373 (Tasmap 1:100 000 *TAMAR*, Sheet 8215) The meandering stream channel that formerly occured at the break of slope at the foot of the Dazzler Range has been artificially straightened during the course of pasture improvement.

Following a heavy rainfall event during the period 2–6 April 1989, an erosion gully which had formed across the alluvial fan in the lower reaches of Branchs Creek and had shown increased activity since the start of that year, extended rapidly headwards for ~300 m. The erosion was focussed where the stream channel had been artificially straightened. Erosion of the gully led to the filling of a large farm dam downstream with sediment and also to damage to surrounding pasture. Insufficient data are available to allow the rainfall intensity responsible for this rainfall event to be calculated but, by analogy with flood discharge records for two nearby catchments, O'Loughlin (1991) suggested that the peak flow experienced in lower Branchs Creek was 21.8 cumecs, the recurrence interval for flows of this magnitude being ~15 years.

From the dimensions and bed slope of the undisturbed channel immediately upstream from the eroded area, O'Loughlin (1991) calculated a bank-full flow velocity and discharge of 1.32 m/sec and 8.0 cumec respectively, compared to 5.22 m/sec and 117.0 cumecs for the artificially modified section of channel. Discharge through the modified channel exceeded the capacity of the unmodified channel by a factor of 12. Discharge in excess of 8 cumecs through the unmodified channel would result in overbank flow that would lead to dissipation of erosive energy across the vegetated floodplain, with negligible erosion potential (O'Loughlin 1991).

The gully that formed across the fan extended headward for several hundred metres, upstream from the pasture where the channel had been modified, into forested land. The gully was generally up to 5 m deep and 10 m wide. Towards its upstream end, sections up to 6 m deep were incised through the fan sediments, with large logs present at the base of some sections. The stratigraphy of the sediments exposed in the sections along the walls of the gully during the winter of 1991 is presented in figure 2 (A,B,C,D).

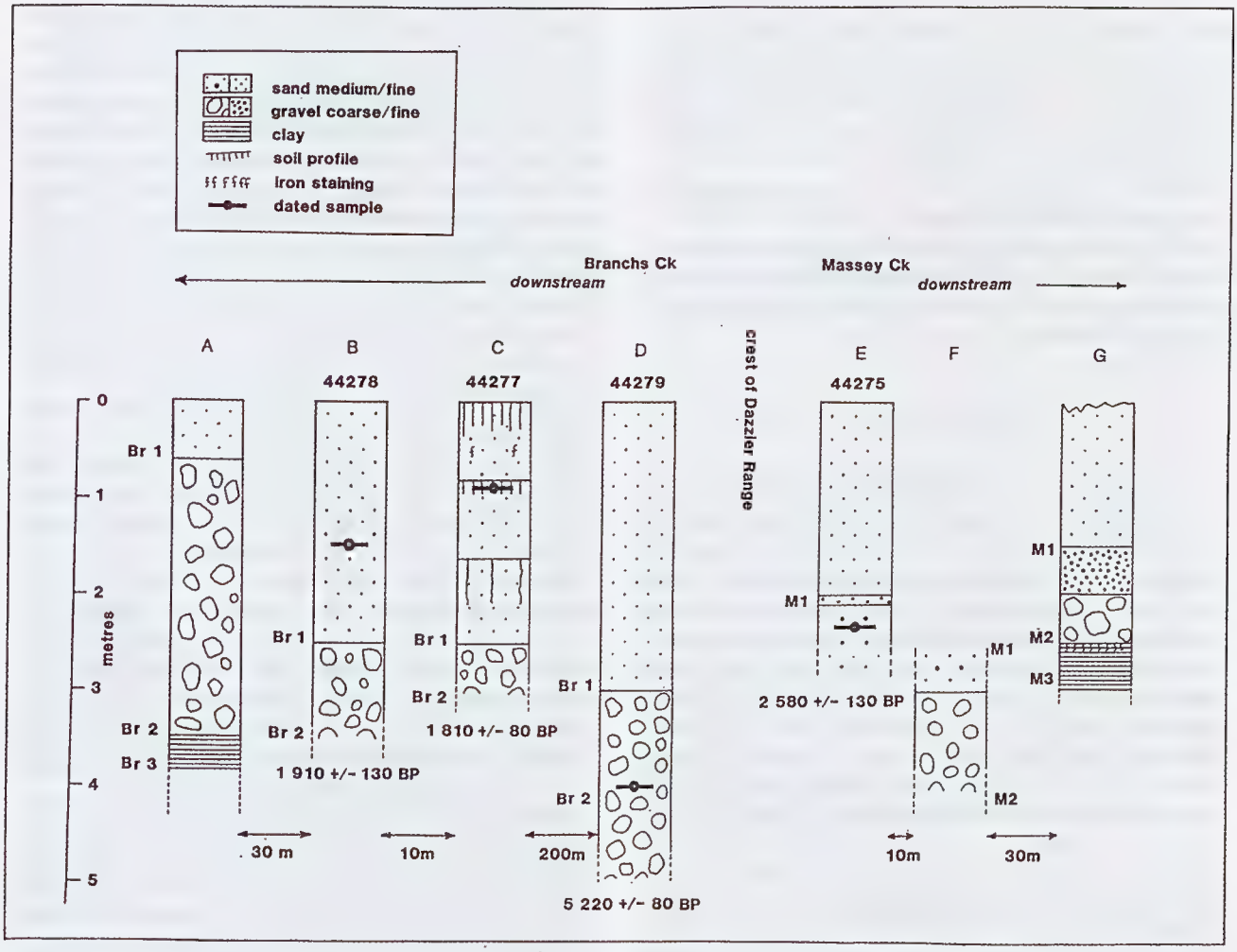


FIG. 2 — Sections through the Branchs Creek sediments (A, B, C, D) and Massey Creek sediments (E, F, G).

Unit Br1, the uppermost unit, comprises up to 3 m of sands. The upper 0.30 m or so comprises a soil profile of A-Cox-Cu type (Birkeland 1984) developed in the sands. In one section, poorly developed palaeosols were evident at 0.80–0.95 m depth, and possibly at 1.6–2.1 m depth, with light iron-staining of the sands in some cases evident at depths of 2 m or more. Lenses and beds of fine gravel a few centimetres thick were present, particularly towards the base of the unit. The mean calibre of these gravels is < 25 mm, the largest clasts being ~50 mm in diameter.

Unit Br2 comprises a bed of coarse gravels at least 2 m thick. The clasts are commonly 0.10–0.15 m in diameter, the largest clast observed being ~1.4 m long. The gravels comprise sandstones and metamorphic rocks derived from further upstream within the Branchs Creek catchment. Similar gravels are exposed in streambank sections at up to 110 m altitude in several other locations for at least 7 km further upstream. Large pieces of wood, including logs 3–4 m long and up to 0.5 m diameter, occur within the uppermost part of this unit.

Unit Br3 consists of dense clay at least 1 m thick.

Organic material was retrieved for radiocarbon assay from three horizons in these alluvial sediments. Charcoal from within a palaeosol at 0.80–0.95 m depth in 2.5 m of unit Br1 sands gave an age of 1810 ± 80 yr BP (Beta 44277). A sample comprising a combination of charcoal and wood fragments from 1.5 m depth in a 2.5 m thick exposure of unit Br1 sands gave an age of 1910 ± 130 yr BP (Beta 44278). A wood fragment from 1 m depth in an exposure of unit Br2 gravels overlain by 3 m of unit Br1 sands returned a radiocarbon age of 5220 ± 80 yr BP (Beta 44279).

MASSEYS CREEK SEDIMENTS

Masseys Creek drains eastwards from the Dazzler Range to the West Arm of Port Dalrymple, the Tamar River estuary. Like Branchs Creek, Masseys Creek has formed an alluvial fan, the apex of which lies at ~ 30 m altitude, ~2 km from tidewater and 9 km inland from the northern coastline of Tasmania. In the lower reaches of Masseys Creek, a gully up to 3–4 m deep has formed within the alluvial fan on the lower slopes, following clearing and artificial straightening of the stream channel (Tamar 795438). The stratigraphy exposed is presented in figure 2 (E, F, G).

Unit M1, the uppermost, comprises up to 3.5 m of sand. In one section a 0.1 m thick lens of fine gravel occurred at 2 m depth, but in another section a 0.4–0.6 m thick bed of fine gravels was sandwiched between 1.6 m of sand and underlying coarse gravels.

Unit M2 comprises coarse gravels in which some

individual cobbles reached 0.1–0.15 m diameter. In one section at least 1 m of coarse gravels was exposed, while in another only half that thickness was present, sandwiched between 0.4–0.6 m of fine gravels, interpreted as part of unit M1, and an underlying clay bed. These gravels comprise Precambrian sandstone and metamorphic rocks from higher in the Masseys Creek catchment.

Unit M3 comprised grey clay with some iron staining in the uppermost few centimetres.

A sample of charcoal and wood fragments was obtained from 2.2 m depth in unit M1, slightly below a 0.1 m thick bed of fine gravel. This returned a radiocarbon age of 2580 ± 130 yr BP (Beta 44275).

DISCUSSION

From the catalogue of Tasmanian radiocarbon dates compiled by Colhoun (1985) it is evident that radiocarbon assay results of broadly comparable age have been obtained from wood and charcoal in alluvial sediments from a number of other parts of Tasmania. For example, Caine (1978, 1983) has reported a date of 3940 ± 110 yr BP (Beta 2109) for charcoal in slope deposits at Pig Run Creek at Ben Lomond in northeastern Tasmania. The results from the Dazzler Range also bear comparison with a major phase of gravel deposition from ~6.5 ka to ~3 ka in the Tea Tree Rivulet valley near Buckland in southeastern Tasmania (Goede 1965, 1973). However, the circumstances under which these sediments have accumulated remain unresolved.

The dated sequence of alluvial sediments at Branchs Creek on the western side of the Dazzler Range attests to considerable hillslope instability and alluvial sedimentation during the latter part of the Holocene. The very similar stratigraphy 12 km away, on the eastern side of the range at Masseys Creek, and the broadly similar age of the sediment there indicate that the aggradation at this time was not a localised phenomenon.

The radiocarbon date obtained from a log buried in the upper part of the Unit Br 2 gravels is not entirely conclusive evidence for the age of the gravels. Nanson *et al.* (1995) found that logs of long-lived and rot resistant Huon pine (*Lagarostrobos franklinii*) in the present channel of the Stanley River in western Tasmania commonly yielded radiocarbon ages of up to 2 ka. While the longevity of the timber in the channel of Branchs Creek may be less than that of Huon pine logs in the Stanley River channel, the possibilty remains that the uppermost Branchs Creek gravels are significantly younger than the logs they contain. However, the possibility that contamination of the wood sample by younger humic acids may have given rise to an erroneously young date must also be allowed.

Weathering of the sandstone on some slopes of the Dazzler Range has produced small angular blocks that have been incorporated into slope deposits providing a ready source for the gravels along the valley bottoms. However, there is little to suggest that significant volumes of this material are being delivered into the stream channels today. Unit Br2 comprises clasts that are beyond the competence of the present stream to mobilise, other than under flood conditions. The presence of a considerable thickness of sands overlying the gravels along the floor of the Branchs Creek valley suggests that, under the present vegetation cover, coarse gravels are not normally being mobilised.

In more alpine environments, transitions from the aggradation of coarse alluvial gravels during the LGM to the deposition of only finer sands and gravels during the Holocene have commonly been interpreted as resulting from initially greater mechanical weathering and reduced slope stability, under colder and drier conditions when forest biomass was less than now, followed by the production of finer calibre weathering products after chemical weathering processes became more pronounced, under more stable, forested conditions, once the climate ameliorated (Colhoun 1982). A related situation has been reported from the Stanley River valley in lowland western Tasmania (Nanson *et al.* 1995). However, the radiocarbon evidence from lower Branchs Creek indicates that at least some of the gravels considerably postdate the LGM.

Mid to late Holocene reworking of clasts produced under earlier cold climate conditions seems a likely origin for these dated gravels, but a mechanism that would allow their liberation is required. Localised high magnitude–relatively low frequency events, such as landslides, would have the potential to do so, but such activity appears to be infrequent in the Dazzler Range, where Grant *et al.* (1995) assessed the landslide risk to range from negligible to moderate, depending upon slope. While the gravels have been reworked to a limited degree during catastrophic erosion events, such as those responsible for incision of the Branchs Creek and Masseys Creek gullies, in some instances they have proved relatively resistant to erosion, even forming a small knickpoint waterfall at Masseys Creek.

Slope instability in response to tectonic activity is conceivable. Fire, perhaps anthropogenic, is another possibility. Hughes & Sullivan (1981) have argued that Aboriginal burning could have been the major, if not sole cause of a major phase of landscape instability in eastern NSW in the late Holocene. However, there is no evidence to implicate Aborigines in the catchment instability evident in the Dazzler Range. The present vegetation suggests that parts of the Dazzler Range are an oasis of relatively low fire frequency at present (Brown & Buckney 1983). Some analogy might be possible between the situation in the Dazzler Range in the past and present conditions inland of St Marys on Tasmania's east coast. There, dissected hills formed of Mathinna rocks exhibit wet sclerophyll and fern communities in protected gullies and much more open forest with limited ground cover and high fire frequencies on the north-facing slopes and ridges (F. Duncan, pers. comm.).

A climate-driven change towards a more open vegetation structure coupled with associated changes in fire frequency would provide a plausible explanation for the dated Unit Br2 gravels at Branchs Creek. Macphail (1981) argued that climate has predominated over fire in determining the nature of Tasmania's vegetation during the Holocene. Tasmanian palynological records have generally proved too insensitive to allow detailed insight into Holocene climatic events and, at any rate, they do not readily allow discrimination between changes in temperature and changes in rainfall. However, Macphail (1981) suggested that many Tasmanian forests became more open in structure and sclerophyll-enriched after ~7–6 ka, and that, during this period, climates became more variable, drought and frost-prone. Markgraf *et al.* (1986) suggested that maximum Holocene precipitation levels in southwestern Tasmania were attained from 8-6 ka after which conditions became considerably drier.

While some Holocene slope deposits and valley fills elsewhere in Tasmania have previously been attributed to a phase of mid Holocene aridity (Davies 1974), no convincing independent evidence for such a phase has been forthcoming. On the other hand, oxygen-isotope analysis of a speleothem from Lynds Cave at Mole Creek in central northern Tasmania indicates colder conditions than now during the late Holocene, with conditions of maximum cold at ~3.8 ka (Goede & Hitchman 1984). A further palaeotemperature record from a speleothem from Frankcombes Cave in the Florentine Valley, south central Tasmania, suggests temperatures were 2–3°C colder than now at ~4.1 ka, and were nearly as low on at least four other occasions between 3.8 ka and 3.0 ka (Goede *et al.* 1990). At similar southern latitudes in New Zealand, there is also evidence that the marked warming that occurred after ~9 ka terminated with neoglacial cooling that commenced at ~5 ka. Numerous well-documented glacier fluctuations have occurred since that time, these advances having diminished only slightly in size towards the present (Chinn 1996). Such palaeoclimatic evidence points towards the possibility of temperature-driven vegetation changes and associated aggradation in the Dazzler Range during the mid-late Holocene.

The Dazzler Range is at present forested to its summit, the vegetation on the higher parts of the range being a complex of eucalypt forest including *Eucalyptus delegatensis*, with varying understorey, and rainforest. Assuming the standard lapse rate of 0.6°C/100 m (Cole 1975), the suggested relative temperature depression of 3°C during the late Holocene would imply a shift in vegetation boundaries on the Dazzler Range by ~500 m, all other factors being equal. While the *E. delegatensis* forest could be expected to move downslope, the summit of the range would not emerge above tree-line. Kirkpatrick & Brown (1984) have identified the Dazzler Range as being one of seven centres of local higher plant endemism in Tasmania. They suggested that the species involved may have evolved before the Last Glacial, and, if so, probably occupied the same geological substrate during the colder and drier conditions that prevailed then. From this they conclude these species could be expected to tolerate much lower temperatures than at present. Infrequent extreme events may be more significant in eliminating elements of the vegetation than temperature decline alone, but in this scenario recovery is likely to be relatively rapid. Short-term vegetation removal by clear-fall forestry under present climatic conditions has not produced the degree of landscape instability evident from the Branchs Creek and Massey Creek deposits. It seems most probable that the recycling of relict gravels from the Dazzler Range to form unit Br2 was facilitated by an interaction between neoglacial cooling and the development of a more open vegetation structure.

Vegetation response is likely to lag behind climate change (Colhoun *et al.* 1991), and should rainfall increase more rapidly than the vegetation cover, a significant increase in runoff and sediment yield may result. Nanson *et al.* (1995) proposed that the advent of large trees on the banks of the Stanley River in western Tasmania and the subsequent accumulation of log debris in the channel would have increased flow resistance and reduced stream power, boundary shear stress and the grain size of the sediment load, during a period interpreted by Markgraf *et al.* (1986) as one of increased overall precipitation. The Stanley River appears to have stabilised in its present channel at 3.5–3.2 ka, with complete stabilisation in the channel occurring after this. This was interpreted by Nanson *et al.* (1995) as being the result not of any detectable vegetation change but of a change in climate and a reduction in flow regime evident from a decline in channel capacity and sediment texture.

The radiocarbon dating from the Dazzler Range implies that during the late Holocene only fine calibre sediment has been deposited upon the coarse gravels, albeit in abundance. The reduction in the calibre of the sediments seems most likely to have been related to vegetation changes. The abundance of charcoal in the upper sand units at both Branchs Creek and Masseys Creek suggests there was fire activity at various times during the period over which they accumulated. The presence of weakly developed buried palaeosols in the Br1 sands indicates that this unit was not deposited in a single event.

While the sands appear to postdate ~2 ka their precise age is uncertain, since the radiocarbon deteminations were performed upon charcoal fragments that might considerably predate accumulation of the sediment within which they occur. For example, Blong & Gillespie (1978) have shown that the age of charcoal being carried in the present flotation load of the McDonald River in NSW varies from ~650 yr BP for larger fragments to ~1550 yr BP for more comminuted particles. The limited soil profile development in the sands adjacent to both Branchs Creek and Masseys Creek suggests some ongoing surface instability adjacent to both stream channels.

CONCLUSIONS

The age of the basal part of the coarse gravel fills in the Branchs Creek and Massey Creek valleys is unresolved, but at least the upper part of this unit appears to date from the mid Holocene. Likely explanations for the aggradation of coarse sediment in valleys draining the Dazzler Range at this time are slope instability and the reworking of older deposits, facilitated by a shift towards a more open vegetation structure caused by neoglacial cooling. However, there is insufficient data to confirm this as the causal factor. Fire has probably played a significant role in erosion and the aggradation of finer sediment since that time. The volume of sediment that has accumulated during the late Holocene in the lower Branchs Creek and Masseys Creek valleys, even under natural forested conditions, and the strong response of the stream channels on the lower slopes to artificial modification suggest that cautious land management is required in the Dazzler Range.

ACKNOWLEDGEMENTS

I am grateful to Fred Duncan, Andy North, Nathan Duhig, Eric Colhoun and Albert Goede for helpful discussions regarding various aspects of this work. I would also like to thank Mick Brown and an anonymous referee for comments on the manuscript.

REFERENCES

BIRD, J.F., 1985: Review of channel changes along creeks in the northern part of the Latrobe River Basin Gippsland, Victoria, Australia. *Z. Geomorphol.* NF 55: 97-111.

BIRKELAND, P.W., 1984: *SOILS AND GEOMORPHOLOGY.* Oxford University Press, New York.

BLONG, R.J. & GILLESPIE, R., 1978: Fluvially transported charcoal gives erroneous ^{14}C ages for recent deposits. *Nature* 271: 739-741.

BROWN, M. J. & BUCKNEY, R.T., 1983: Structural and floristic variation in the forest communities of the West Tamar, Tasmania. *Pap. Proc. R. Soc. Tasm.* 117: 135-152.

CAINE, N., 1978: Late Holocene instability on hillslopes in northeastern Tasmania. *Search* 9: 298.

CAINE, N., 1983: *THE MOUNTAINS OF NORTHEASTERN TASMANIA.* Balkema, Rotterdam.

CHINN, T.J., 1996 The Southern Hemisphere glacial record — Antarctica and New Zealand. In Banks, M.R. & Brown, M.J. (Eds): *CLIMATIC SUCCESSION AND GLACIAL HISTORY OF THE SOUTHERN HEMISPHERE OVER THE LAST FIVE MILLION YEARS. Pap. Proc. R. Soc. Tasm.* 130(2): 17-24.

COLE, F., 1975: *INTRODUCTION TO METEOROLOGY.* Wiley, New York.

COLHOUN, E.A., 1977: Late Quaternary fan gravels and slope deposits at Rocky Cape, northwestern Tasmania: their palaeoenvironmental significance. *Pap. Proc. R. Soc. Tasm.* 111: 13–28.

COLHOUN, E.A., 1982: A comparison of the major effects of geomorphic processes in Tasmania during the Last Glacial Stage and the Holocene Stage. *HOLOCENE RESEARCH IN AUSTRALIA.* Occ. Pap. 33, Dep. Geogr., Fac. Mil. Stud., Univ. NSW, Duntroon.

COLHOUN, E.A., 1985: Radiocarbon dates for Tasmania, 1956-1984. *Pap. Proc. R. Soc. Tasm.* 119: 39–54.

COLHOUN, E.A., 1986: Field problems of radiocarbon dating in Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 1–6.

COLHOUN, E.A., VAN DER GEER, G. & FITZSIMONS, S.J., 1991: Late Glacial and Holocene vegetation history of Governor Bog, King Valley, western Tasmania, Australia. *J. Quat. Sci.* 6: 55–66.

COLHOUN, E.A., HANNAN, D.G. & KIERNAN, K., 1996: Late Wisconsin Glaciation of Tasmania. *In* Banks, M.R. & Brown, M.J. (Eds): *CLIMATIC SUCCESSION AND GLACIAL HISTORY OF THE SOUTHERN HEMISPHERE OVER THE LAST FIVE MILLION YEARS. Pap. Proc. R. Soc. Tasm.* 130(2): 33–45.

DAVIES, J.L. 1972: *GEOGRAPHICAL VARIATION IN COASTAL DEVELOPMENT.* Oliver and Boyd, Edinburgh: 204 pp.

DAVIES, J.L. 1974: Geomorphology and Quaternary environments. *In* Williams, W.D (Ed.): *BIOGEOGRAPHY AND ECOLOGY OF TASMANIA*: Junk, The Hague: 17–27.

FISH, G.J. & YAXLEY, M.L., 1966: *BEHIND THE SCENERY.* Education Department, Tasmania.

GEE, R.D. & LEGGE, P.J., 1970: *BEACONSFIELD, TASMANIA. Tasm. Dep. Mines Geol Atlas 1 Mile Series*, Sheet 30 (8215N).

GOEDE, A., 1965: The geomorphology of the Buckland Basin. *Pap. Proc. R. Soc. Tasm.* 99: 133–154.

GOEDE, A., 1973: Floodplain stratigraphy of the Tea Tree Rivulet. *Aust. Geogr. Stud.* 11: 28–39.

GOEDE, A & HITCHMAN, M.A., 1984: Late Quaternary climatic change: Evidence from a Tasmanian speleothem. *In* Vogel, J.C. (Ed.): *LATE CAINOZOIC PALAEOCLIMATES OF THE SOUTHERN HEMISPHERE.* Balkema, Rotterdam: 221–232.

GOEDE, A., VEEH, H.H. & AYLIFFE, L.K., 1990: Late Quaternary palaeotemperature records for two Tasmanian speleothems. *Aust. J. Earth Sci.* 37: 267–278.

GRANT, J.C, LAFFAN, M.D., HILL, R.B. & NEILSEN, W.A., 1995: *FOREST SOILS OF TASMANIA.* Forestry Tasmania, Hobart: 189 pp.

HUGHES, P.J. & SULLIVAN, M.E., 1981: Aboriginal burning and late Holocene geomorphic events in eastern NSW. *Search* 12(8): 277–278.

KIRKPATRICK, J.B. & BROWN, M.J., 1984: The palaeogeographic significance of local endemism in Tasmanian higher plants. *Search* 15 (3-4): 112–113.

MACPHAIL, M.K., 1981: A history of fire in the forest. *In* Kirkpatrick, J.B. (Ed.): *FIRE AND FOREST MANAGEMENT IN TASMANIA*:. Tasmanian Conservation Trust, Hobart: 15–22.

MARKGRAF, V., BRADBURY, J.P. & BUSHBY, J.R., 1986: Paleoclimates in southwestern Tasmania during the last 13,000 years. *Palaios* 1: 368–380.

MURRAY-WALLACE, C. V. & GOEDE, A., 1995: Aminostratigraphy and electron spin resonance dating of Quaternary coastal neotectonism in Tasmania and the Bass Strait islands. *Aust. J. Earth Sci.* 42: 51–67.

NANSON, G.C., BARBETTI, M. & TAYLOR, G., 1995: River stabilisation due to changing climate and vegetation during the late Quaternary in western Tasmania, Australia. *Geomorphology* 13: 145–158.

O'LOUGHLIN, E.M., 1991: Erosion in Branchs Creek. Unpub. rep. to and available from For. Commn, Tasmania, 24 Jul. 1991: 6 pp.

THOM, B.G., BOWMAN, G.M., GILLESPIE, R., TEMPLE, R. & BARBETTI, M., 1981: *RADIOCARBON DATING OF HOLOCENE BEACH-RIDGE SEQUENCES IN SOUTHEAST AUSTRALIA.* Monogr. 11, Dep. Geogr., Univ. NSW R. Mil. Coll., Duntroon.

(accepted 3 February 1998)

NEW LOCALITY RECORDS FOR SOME RARE MOSSES IN TASMANIA

by P.J. Dalton

(with two tables, one text-figure and one plate)

DALTON, P.J., 1998 (31:xii): New locality records for some rare mosses in Tasmania. *Pap. Proc. R. Soc. Tasm.* 132: 41–45. ISSN 0080–4703. School of Plant Science, University of Tasmania, GPO Box 252-55, Hobart, Tasmania, Australia 7001.

Further records of occurrence of four rare mosses, *Seligeria cardotii* R.Br., *Calomnion complanatum* (Hook.f. et Wils.) Lindb., *Ephemeropsis trentepohlioides* (Rem.) Sainsb. and *Papillaria flexicaulis* (Wils.) Jaeg., are provided as well as notes on their habitat and distinguishing features.

Key Words: mosses, *Seligeria, Calomnion, Ephemeropsis, Papillaria,* Tasmania.

INTRODUCTION

There have been more than 640 species of bryophytes recorded for Tasmania, comprised of 282 hepatic species (Ratkowsky 1987) and 361 moss species (Dalton *et al.* 1991). This number of species is significant when compared to other groups of land plants and, therefore, the bryophytes represent a major component of the flora (table 1).

Since the publication of an annotated checklist of Tasmanian mosses (Dalton *et al.* 1991), further collecting, and taxonomic and ecological research on the flora have continued, resulting in some additions and further distributional records for many species. Moscal & Kirkpatrick (1997) presented distribution maps of mosses and liverworts in Tasmania with the intention of establishing their reservation and conservation status. However, for a number of the rarer species data were not included, or information was based on old collections and/or literature records. In this paper, new records for the distribution of four interesting and rare mosses in Tasmania are reported, and their importance to the diversity of the bryoflora is discussed.

TABLE 1
The estimated number of native species in different plant groups

	Species	% endemics
Lichens*	762	-
Bryophytes† (moss & hepatic)	643	8
Pteridophytes‡ (ferns & allies)	98	5
Gymnosperms‡ (conifers)	11	80
Angiosperms‡: Monocots	539	14
Angiosperms‡: Dicots	943	25

* Kantvilas 1994.
† Ratkowsky 1987 and Dalton *et al.* 1991.
‡ Buchanan 1995.

METHODS

This study is based on verified herbarium collections (CANB and HO) and field collections made in Tasmania by the author. All new collections are deposited in the Tasmanian Herbarium (HO), with duplicates held in the author's private herbarium. Determination of species is based on comparisons with reliably identified reference material and/or literature descriptions. Scanning electron microscopy used one of the following procedures:
(1) fresh material observed in an ESEM Electro Scan 2020 in wet mode (cold stage), or
(2) fresh material fixed in 2% Osmium tetroxide, dehydrated in acetone series, rinsed twice in Hexamethyldisilazone (HMDS), air dried, sputter coated with gold and then observed under HIVAC in a ESEM Electro Scan 2020.

RECORDS

Seligeria cardotii R. Br.

This minute epilithic moss is the only species of the genus that has been recorded for Tasmania. Plants, which form a loose assemblage on limestone, are erect, up to 2 mm high and light green when moist. The leaves are linear with a prominent midrib which is narrow at the base but wider above. The mid-leaf cells are clear and rectangular in 2–3 rows each side of the midrib. A fuller description and illustration of the Tasmanian material has been presented by Dalton (1995).

This calcicolous moss was previously considered a species endemic to New Zealand (Sainsbury 1955), where it has a widespread distribution. The first record of it occurring in Tasmania was reported from Dogs Head Hill, Mole Creek, where it grew on damp limestone in dry sclerophyll forest (Dalton 1955). A new record (P.J. Dalton 94.220, 9.xii.1994) is reported from a similar substrate, moist calcareous rockface, but in a more protected habitat in refuge rainforest (*Nothofagus cunninghamii/Atherosperma moschatum*)in the upper part of the Junee Valley, adjacent to Mt Field National Park (fig. 1A). This species may have a greater distribution on suitable calcareous substrate in Tasmania, but it has possibly been overlooked due to its small size and specific substrate.

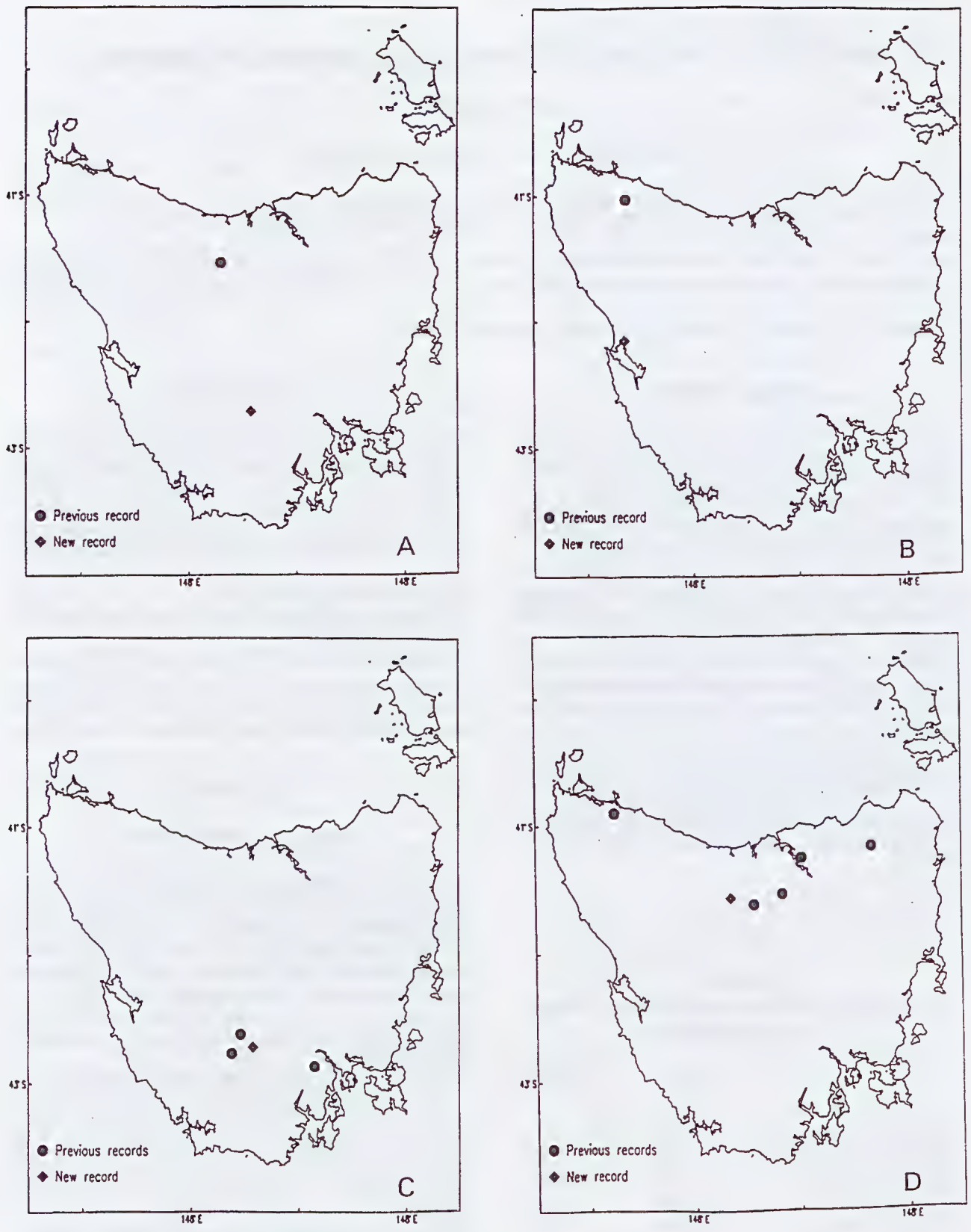


FIG. 1 — The distribution of (A) Seligeria cardotii, *(B)* Calomnion complanatum, *(C)* Ephemeropsis trentepohlioides, *(D)* Papillaria flexicaulis.

Calomnion complanatum (Hook. f. et Wils.) Lindb.

This is the sole species of the genus in the Tasmanian flora and is characterised by simple shoots which bear leaves in three ranks in the upper part of the stem but are often denuded below. The leaves of the two lateral rows are oblong, while smaller orbicular leaves form a dorsal row (pl. 1A). There is a distinct midrib, which is percurrent, and the leaf margin varies from entire to slightly crenulate. A fuller description can be found in Vitt (1995), and Stone (1990) provided a detailed description of the persistent heterotrichous protonema.

The species was first recorded for Tasmania growing as an epiphyte on the fibrous trunk of *Dicksonia antarctica* beside the track at Dip Falls, near Stanley (Stone 1990), although Vitt (1995) reported a Tasmanian collection (NY) without locality made by Gunn. A new record (P.J. Dalton 95.18, 23.v.1995) is reported from the Hogarth Falls track, Strahan (fig. 1B), where it was growing on the trunk of a tree fern, which appears to be the preferred substrate. The leaves of *C. complanatum* are highly deciduous and probably act as vegetative propagules. It could be postulated that this may have aided the recent occurrence and distribution of the species at the two known localities, which are popular tourist destinations.

Ephemeropsis trentepohlioides (Rem.) Sainsb.

This moss is characterised by an extremely reduced gametophyte made up of a fine brownish filamentous protonema which could easily be overlooked in the field. It is readily recognised as a moss with the presence of minute setae (c. 2 mm long) bearing tiny erect capsules (pl. 1B), which arise from small perichaetial bracts. The calyptra is mitriform with a fringed base, and the outer peristome is short, with the 16 teeth bent back over the opened capsule when dry (pl. 1C). Spores are large, elongate and multicellular (pl. 1D). This is probably the most extraordinary moss in the flora and has been described by Willis (1953).

This unique epiphytic moss, which is widespread on both North and South Islands of New Zealand (Beever *et al.* 1992), was first recorded in Tasmania from the Florentine Valley (Willis 1953). A further collection from the same area was made by Norris (HO 93460) and, more recently, a collection from Myrtle Gully, Collinsvale (D. Glenny, pers. comm.). A new record (P. J. Dalton 94.215, 9.xii.1994) is reported from the upper part of Junee Valley (fig. 1C), where the species was an abundant epiphyte on living and dead twigs of *Atherosperma moschatum*. It was most abundant at the edge of refuge rainforest, where light penetration is favourable.

Papillaria flexicaulis (Wils.) Jaeg.

This epiphytic species is characterised by long, slender, pendulous dull-green shoots. The leaves are narrowly triangular, imbricate and tightly appressed to the stem when dry (pl. 1E), but when moist rapidly stand at right angles to the stem. The nerve is faint and extends to three-quarters of the leaf. The cells are rhomboidal throughout, and in the mid-leaf and above are densely papillose, with the papillae extending to the margins of the leaf (pl. 1F). A detailed description was given by Streimann (1991).

Three other species of *Papillaria* occur in Tasmania: *P. flavolimbata* is the commonest species, with robust yellowish-green shoots which often taper to very slender shoots. The leaves are extremely undulate, and the papillae do not extend to the margins of the leaf. *P. crocera* is a similar species, but the smooth cells at the margin of the leaf are shorter. *P. nitens* has finer, softer shoots, and the leaf cells are not obscured with dense papillae as in the previous species.

Papillaria flexicaulis is a widespread moss on the Australian mainland and would appear to reach its southern limit in northern Tasmania (Streimann 1991). Nine collections have been recorded, and eight of these were made in the late 19th century (Circular Head, Westbury, Deloraine and East Tamar). The impact of human occupation at these localities during the past century would cast doubt on the continuing survival of the species. The only previous collection during the last 100 years was made in 1974, in moist eucalypt forest near Scottsdale (Norris HO94217). A new record (P.J. Dalton 94.43, 28.i.1994) is reported from Sassafras Ridge, Mole Creek (fig. 1D), where the species occurred as a pendulous epiphyte on *Pomaderris apetala* and *Olearia argophylla* in eucalypt forest.

DISCUSSION

The mosses *Seligeria cardotii*, *Calomnion complanatum*, *Ephemeropsis trentepohlioides* and *Papillaria flexicaulis* have limited distribution in the Tasmanian vegetation. In contrast, all four species are widely distributed on both North and South Islands of New Zealand, while *P. flexicaulis* is the only species with widespread distribution on mainland Australia. There are strong affinities of the Tasmanian bryoflora to New Zealand and southeastern Australia (Victoria and NSW) and, in the case of the mosses, as much as three-quarters is shared with those areas (Scott & Stone 1976, Beever *et al.* 1992).

An alternative comparison of the bryofloras can be made by determining the diversity or richness, which can be expressed as the number (genera and/or species) per logarithmic area. The diversity of the Tasmanian bryoflora compared with floras in other temperate regions is evaluated in table 2. These numbers are approximations only, since taxonomic revisions and biogeographic studies will inevitably result in further changes. The species diversity of mosses in Tasmania is less than in southeastern Australia (Victoria and NSW) and much less than in New Zealand. However, the hepatics are considerably more diverse than those of Victoria but, like the mosses, are markedly less so than in New Zealand. Of the Gondwanan land masses (i.e. New Zealand, southern Australia, Tasmania and southern Africa), New Zealand contains the greatest diversity of bryophytes, which is in agreement with previous comparative studies (Fife 1985).

The diversity of the Tasmanian mosses may not be as impressive as other floras. Nevertheless, the specialised habitats that are occupied by such epiphytic species as *C. complanatum*, *E. trentepohlioides* and *P. flexicaulis* and the epilithic species *S. cardotii* are an important component of the floristics of the Tasmanian vegetation. Three of the species are the sole representatives of genera in Tasmania, and all four occupy habitats and substrates that may be

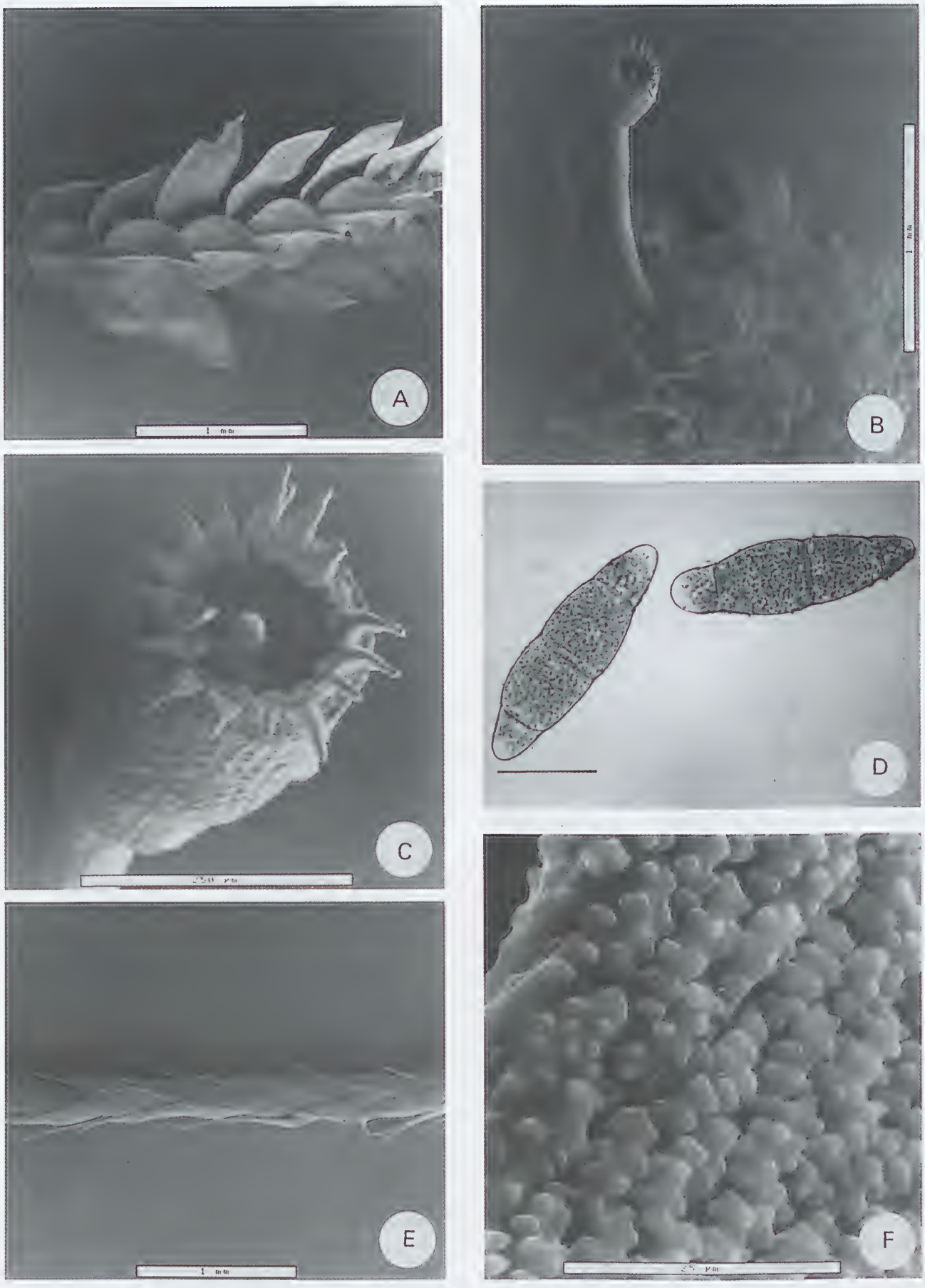


PLATE 1

(A) ESEM (Hivac) whole shoot of Calomnion complanatum, *(B) ESEM (Hivac) whole shoot with capsule of* Ephemerophsis trentepohlioides, *(C) ESEM (Hivac) capsule with peristome of* E. trentepohlioides, *(D) LM Spores of* E. trentepohlioides, *Scale bar 50 µm, (E) ESEM (Hivac) whole shoot of* Papillaria flexicaulis, *(F) ESEM (wet mode) leaf surface with papillae of* P. flexicaulis.

TABLE 2
The number of genera and species of mosses and hepatics in comparable temperate geographic regions

Geographic region*	No. of species	No. of genera	No. of species per ln. (km²)	No. of genera per ln. (km²)
Mosses				
Tasmania[1]	361	141	32.4	12.7
NSW[2]	527	171	38.8	12.6
Victoria[3]	500	150	40.5	12.2
South Aust.[4]	179	79	13.0	5.7
West Aust.[5]	192	78	13.0	5.3
New Zealand[6]	523	208	41.8	16.6
Europe[7]	1052	232	65.4	14.4
British Isles[8]	692	175	54.7	13.8
southern Africa[9]	591	191	39.9	12.9
Hepatics				
Tasmania[10]	282	96	25.3	8.6
Victoria[3]	230	84	18.6	6.8
New Zealand[11]	569	142	45.5	11.4
US & Canada[7]	500	129	29.8	7.7
Europe[7]	434	104	27.0	6.5
southern Africa[9]	316	92	21.4	6.2

* (1) Dalton *et al.* 1991, (2) Ramsay 1984, (3) Cropper *et al.* 1991, (4) Catcheside 1980, (5) Stoneburner *et al.* 1993, (6) Fife 1995, (7) Fife 1985, (8) Smith 1980, (9) Magill & Schelpe 1979, (10) Ratkowsky 1987, (11) Glenny, pers. comm. 1995 (unpubl. checklist).

vulnerable in much of the vegetation. Therefore, further studies are needed to identify the distribution of these species as well as other rare or less well-documented bryophytes, in order to maintain our knowledge of the diversity of the bryoflora in Tasmania.

ACKNOWLEDGEMENTS

I thank Michael Lichon and Dr Greg Jordan for field assistance, Wieslaw Jablonski of the Central Science Laboratory, University of Tasmania, for taking the SEM photographs and Greg Dutkowski for help in producing the distribution maps.

REFERENCES

Beever, J., Allison, K.K. & Child, J., 1992: *THE MOSSES OF NEW ZEALAND.* University of Otago Press, Dunedin.

Buchanan, A.M., 1995: A census of the vascular plants of Tasmania and index to The Student's Flora of Tasmania. *Occ. Publ. Tasm. Herb. 5.*

Catcheside, D.G., 1980: *MOSSES OF SOUTH AUSTRALIA.* Government Printer, Adelaide.

Cropper, S.C., Tonkinson, D.A. & Scott, G.A.M., 1991: *A CENSUS OF VICTORIAN BRYOPHYTES.* Dep. of Conservation and Environment, Victoria.

Dalton, P.J., 1995: *Seligeria cardotii* R. Br., a new moss record for Tasmania. *NZ J. Bot.* 33: 143–145.

Dalton, P.J., Seppelt, R.D. & Buchanan, A.M., 1991: An annotated checklist of Tasmanian Mosses. *In* Banks, M.R. *et al.* (Eds): *ASPECTS OF TASMANIAN BOTANY —A TRIBUTE TO WINIFRED CURTIS.* Royal Society of Tasmania: 15–32.

Fife, A.J., 1985: Biosystematics of the crytogamic flora of New Zealand: Bryophytes. *NZ J. Bot.* 23: 645–662.

Fife. A.J., 1995: Checklist of the mosses of New Zealand. *Bryologist* 98(3): 313–337.

Kantvilas, G., 1994: A revised checklist of the Tasmanian lichen flora. *Muelleria* 8: 155–175.

Magill, R.E. & Schelpe, E.A., 1979: The bryophytes of southern Africa. An annotated checklist. *Mem. Bot. Surv. S. Afr.* 43.

Moscal, A. & Kirkpatrick, J.B., 1997: *ATLAS OF MOSSES AND LIVERWORTS IN TASMANIA.* Tasmania Conservation Trust Inc., Hobart.

Ramsay, H.P., 1984: Census of New South Wales mosses. *Telopea* 2(5): 455–533.

Ratowsky, D.A., 1987: Checklist of the Tasmanian liverworts. *Pap. Proc. R. Soc. Tasm.* 121: 153–158.

Sainsbury, G.O.K., 1955: A handbook of the New Zealand mosses. *Bull. R. Soc. NZ* 5.

Scott, G.A.M. & Stone, I.G., 1976: *THE MOSSES OF SOUTHERN AUSTRALIA.* Academic Press, London.

Smith, A.J.E., 1980: *THE MOSS FLORA OF BRITAIN AND IRELAND.* Cambridge University Press, Cambridge.

Stone, I.G., 1990: Nomenclatural changes and new moss record in Australia: including a description of the protonema of *Calomnion. J. Bryol.* 16: 261–273.

Stoneburner, A., Wyatt, R., Catcheside, D.G. & Stone, I.G., 1993: Census of the mosses of Western Australia. *Bryologist* 96(1): 86–101.

Streimann, H., 1991: Taxonomic studies on Australian Meteoriaceae (Musci) I. Introduction and the genus *Papillaria. J. Hattori Bot. Lab.* 69: 203–256.

Vitt, D.H., 1995: The genus *Calomnion* (Bryopsida): Taxonomy, phylogeny and biogeography. *Bryologist* 98(3): 338-358.

Willis, J.H., 1953: Nemataceae, a moss family new to Australia. *Nature* 172: 127–128.

(accepted 5 May 1998)

THE FIRST RECORD OF LARVAE OF THE GIANT CRAB *PSEUDOCARCINUS GIGAS* IN THE PLANKTON

by Caleb Gardner

(with one table)

GARDNER, C., 1998 (31:xii): The first record of larvae of the giant crab *Pseudocarcinus gigas* in the plankton. *Pap. Proc. R. Soc Tasm.* 132: 47–48. ISSN 0080–4703. Tasmanian Aquaculture and Fisheries Institute, GPO Box 252-49, Hobart, Tasmania, Australia 7001.

This note reports the first collection of *Pseudocarcinus gigas* zoeas from the plankton. Plankton samples were collected in November 1992 from oceanic waters on the edge of the continental slope near Pedra Branca, southern Tasmania (longitude 147°09'32"E to 147°28'30"E, latitude 44°11'23"S to 44°12'30"S). Although samples were collected during the period when *P. gigas* larvae would be expected to be abundant, only three stage-2 *P. gigas* zoeas were captured from a total of 342 Brachyuran larvae. All three zoeas were captured in the upper 100 m of water and were from different samples taken during both day and night.
Keywords: plankton, zoeas, *Pseudocarcinus gigas*.

INTRODUCTION

Giant crabs are the basis of a small, high-value fishery in Tasmania, which developed in 1991, mainly around the northeast and northwest of the State. An important aspect of the biology of the species for management is the larval development which influences dispersal and, thus, likelihood of local depletion. Although several laboratory studies have been conducted on the larvae of the giant crab, no larvae or recently settled juveniles have been collected from the wild. Observations on natural distribution are clearly important for validating laboratory studies on vertical migration behaviour (Gardner 1996).

METHODS

Plankton samples were collected from oceanic waters in the vicinity of Pedra Branca off southern Tasmania (within the region, longitude 147°09'32"E to 147°28'30"E, latitude 44°11'23"S to 44°12'30"S) in November 1992. This location is at the southern limit of the range of *P. gigas*, which extends from southern Western Australia to southern New South Wales (McNeill 1920). Based on the catch rates of commercial fishers (Gardner 1998), there appears to be low abundance of adult giant crabs in southern Tasmania relative to more northern areas.

Samples were collected near the edge of the continental shelf, which is where the fishery is based and, also, where larval release is thought to occur (Levings *et al.* 1996). The timing of sampling coincided with the period when larvae would be expected to be in the water column, as hatching occurs in October and November (Gardner 1996). Larval development of *P. gigas* in the laboratory is relatively long, with an average duration of 92 days through five zoeal stages and a megalopa to crab 1 (Gardner & Quintana 1998).

Brachyuran larvae were collected in plankton tows at ten sampling depths, from 10 to 900 m, collected at nine periods over 48 hours. Different depths were sampled in a continuous tow using an EZ plankton net (1 m^2 mouth) deployed from the CSIRO's FRV *Southern Surveyor* (modified Tucker trawl, see Harding *et al.* 1987). Bottom depth ranged from 965 to 1584 m and sampling of plankton tows was at 100 m intervals, from 10 to 900 m depth. The volume of water filtered at each sampling depth ranged between 1650 and 550 m^3 and averaged 1140 m^3. Sampling was conducted almost continually over 14 and 15 November 1992.

Counts of Brachyuran larvae include both zoeas and megalopas. Only higher Brachyuran larvae were sorted from plankton samples, so counts for total Brachyura probably exclude larvae of crabs from the families Homolidae and Dromidae, both of which occur in the region, as they form bycatch from giant crab traps.

RESULTS AND DISCUSSION

A total of 342 Brachyuran larvae were collected and, of these, only three were identified as *Pseudocarcinus gigas*. Identification was based on form of the telson, presence of a dorsal spine on the first abdominal somite, and on the setation patterns of the maxillule and maxillae (full description given in Gardner& Quintana 1998).

All three *P. gigas* larvae were at the second of the five zoeal stages and were found in the upper 100 m (table 1). This depth was also where most of the other brachyuran zoeas were collected. Although few specimens of *P. gigas* were collected, their distribution supports laboratory

TABLE 1
Details of *Pseudocarcinus gigas* zoeas collected in plankton trawls near Pedra Branca on 14–15 November 1992

Specimen number	Sample time (24 hr clock)	Sample depth (m)	Mean temp. (°C)	Density of total Brachyuran larvae (larvae/1000m^3)
1	2.17–4.37	10–100	12.5	161
2	7.09–9.12	10–100	12.5	48
3	16.01–18.55	10–100	12.0	80

observations on the response of *P. gigas* larvae to light, pressure, gravity, currents and temperature. This research predicted that early stage zoeas would be found near the surface at all times of the day, unless temperature exceeded 16.2°C (Gardner 1996, and unpublished data on behavioural response to temperature).

Brachyuran larvae were distributed predominantly in the surface waters, above 100 m, and this distribution did not appear to be affected by time of sampling (approximately 98% of zoeas captured were in the 10–100 m sample). No diel vertical migration cycles were apparent although this may have been due to the low resolution of samples with grouping of zoeas from the upper 100 m. Only one sample appeared to have a different pattern of larval distribution, with most brachyuran larvae at >800 m (midday sample: 11.34–14.30 h: four zoeas in 10–100 m; ten zoeas in 800–900 m). The presence of zoeas at this depth is rare (Rice 1979), although very few larvae were captured in these tows (n = 14), so the unusual depth distribution may be spurious. Temperature declined steadily with depth and there were no indications of thermoclines which may influence larval distribution (McConnaughey & Sulkin 1984).

The presence of very few *P. gigas* larvae in samples is probably due to the southern latitude of the sampling program. Hatching should have occurred prior to the sampling and the presence of stage-2 zoeas also suggests that the plankton sampling was after the peak period of hatch. The duration of the zoeal stages in the laboratory is around 50 days (Gardner & Northam 1997), which indicates that the more benthic megalopa stage would not be found before late December. Consequently, the low capture rate of *P. gigas* zoeas may have been due to limited larval supply at this southerly latitude, although it is also possible that larvae released from this region had been dispersed by currents prior to sampling.

ACKNOWLEDGEMENTS

Erica Aheimer, Andrew Trotter and Josephine Walker provided valuable assistance in sorting and classifying plankton samples. Samples were obtained from the CSIRO with help from Mark Lewis and Dr Barry Bruce. Assistance in the preparation of this manuscript was provided by Dr Greg Maguire. Financial support and facilities were provided by the University of Tasmania and the Tasmanian Department of Primary Industry and Fisheries.

REFERENCES

GARDNER, N.C., 1996: Behavioural basis of depth regulation in the first zoeal stage of the giant crab *(Pseudocarcinus gigas,* Brachyura, Xanthoidea, Oziidae). *HIGH LATITUDE CRABS: BIOLOGY, MANAGEMENT AND ECONOMICS.* Alaska Sea Grant College Program Rep. 96-02. University of Alaska, Fairbanks: 229–253.

GARDNER, C., 1998: The Tasmanian giant crab fishery: a synopsis of biological and fisheries information. Tasm. Dep. Primary Ind. Fish., Int. Rep. 43: 40 pp.

GARDNER, C. & NORTHAM, M., 1997: Use of prophylactic treatments for larval rearing of giant crabs *Pseudocarcinus gigas* (Lamarck). *Aquaculture* 158: 203–214.

GARDNER, C. & QUINTANA, R., 1998: Larval development of the Australian giant crab *Pseudocarcinus gigas* (Lamarck 1818) (Decapoda: Oziidae) reared in the laboratory. *J. Plank. Res.* 20(6): 1169–1188.

HARDING, G.C., PRINGLE, J.D., VASS, W.P., PEARRE, S. JR & SMITH, S.J., 1987: Vertical distribution and daily movements of larval lobsters *Homarus americanus* over Browns Bank, Nova Scotia. *Mar. Ecol. Prog. Ser.* 41: 29–41.

LEVINGS, A., MITCHELL, B.D., HEEREN, T., AUSTIN, C. & MATHESON, J., 1996: Fisheries biology of the giant crab *(Pseudocarcinas gigas,* Brachyura, Oziidae) in Southern Australia. *HIGH LATITUDE CRABS: BIOLOGY, MANAGEMENT AND ECONOMICS.* Alaska Sea Grant College Program Rep. 96-02. University of Alaska, Fairbanks: 125–151.

MCCONNAUGHEY, R.A. & SULKIN, S.D., 1984: Measuring the effects of thermoclines on the vertical migration of larvae of *Callinectes sapidus* (Brachyura: Portunidae) in the laboratory. *Mar. Biol.* 81(2): 139–145.

MCNEILL, F.A., 1920: Studies in Australian carcinology, no. 1. *Rec. Aust. Mus.* 13: 108–109.

RICE, A.L., 1979: A remarkable benthic catch of Portunid crab zoeae (Decapoda, Brachyura). *Crustaceana* Supp. 5: 17–21.

(accepted 28 September 1998)

HELMINTH PARASITE COMMUNITIES IN FOUR SPECIES OF SHOREBIRDS (CHARADRIIDAE) ON KING ISLAND, TASMANIA

by Albert G. Canaris and John M. Kinsella

(with six tables and three text-figures)

CANARIS, A.G. & KINSELLA, J.M., 1998 (31:xii): Helminth parasite communities in four species of shorebirds (Charadriidae) on King Island, Tasmania. *Pap. Proc. R. Soc. Tasm.*, 132: 49–57. ISSN 0080–4703. PO Box 717, Hamilton, Montana, USA 59840 (formerly Department of Biological Sciences, University of Texas at El Paso) (AGC); and Department of Infectious Diseases, College of Veterinary Medicine, University of Florida, Gainesville, Florida, USA 32611 (JMK).

Helminth community composition and structure were examined among two resident shorebird species, red-capped plover, *Charadrius ruficapillus* (N = 20), and masked lapwing, *Vanellus miles* (N = 5), and two migrants, ruddy turnstone, *Arenaria interpres* (N = 20), and curlew sandpiper, *Calidris ferruginea* (N = 5), on King Island, Tasmania in March–April 1993, prior to northward migration to the nesting grounds. The total number of species of helminths recovered was 28 and life cycles of at least 19 of these were occurring on the island. Twenty-five species were categorised as generalists and three were undetermined. One to three species of helminths were dominant in each host species. Eight species, to various degrees, were common among the four species of host. Most sharing occurred in the mucosal trematode guild. Similarities between resident *Charadrius ruficapillus* and migrant *A. interpres* was 32.7%, while the mean number of species and mean number of helminths were significantly higher in *A. interpres*. Except for five new species found in this study, all other species of helminths have been described or reported from charadriids or related hosts from other continents. The pool of helminth parasites capable of infecting shorebirds was well established on King Island.

Key Words: helminth parasites, shorebirds, Charadriidae, *Arenaria interpres*, *Calidris ferruginea*, *Charadrius ruficapillus*, *Vanellus miles*, King Island, Tasmania.

INTRODUCTION

Tasmania and its adjacent islands provide significant habitat to wintering migrant shorebirds (Charadriidae), most of which breed in the Northern Hemisphere, and non-migrating resident shorebirds. King Island, located off the northwest coast of the Tasmanian mainland (40°S, 144°E; 58 km long by 21 km wide), is utilised by and is important habitat for both groups of shorebirds (Schulz 1990). Two migrants, ruddy turnstone, *Arenaria interpres* Linnaeus, and curlew sandpiper, *Calidris ferruginea* Pontoppidian, and two residents, red-capped plover, *Charadrius ruficapillus* Temminick, and masked lapwing, *Vanellus miles* Boddart, were common on King Island at the time of the study (February–March 1993). Ruddy turnstones breed on the coastal plain or lowlands around the Arctic Ocean. They feed on marine invertebrates in rocky areas, on reefs exposed at low tide and in sandy areas with deposits of seaweed. Curlew sandpipers breed mostly on high altitude tundra in Central Siberia and some in northern Alaska. Their preferred foraging areas for invertebrates are muddy areas, including intertidal mudflats (Hayman *et al.* 1986). Masked lapwings breed on King Island and prefer open areas with low vegetation, such as pastures and grasslands (Green 1989, Hayman *et al.* 1986, Slater *et al.* 1989). Some were observed foraging in the intertidal zone at low tide (AGC). Red-capped plovers also breed on King Island (Green 1989, Slater *et al.* 1989) and were observed mostly on open ocean sandy beaches, sandy patches between rocky areas and in areas with deposits of seaweed (AGC).

Many wader species throughout the world have been subjected to diminished and altered habitat. As environmental change continues, overcrowding and stress, factors known to alter host–parasite relationships (Esch *et al.* 1975, Friend 1992), will probably increase. To detect changes in these relationships and their effect on avian morbidity and mortality, analyses of parasite community composition and structure are necessary to establish norms.

Smith (1974, 1983), working in southern Tasmania, elucidated several helminth life cycles and described several species of helminths which used charadriids as definitive hosts. Deblock & Canaris (1996, 1997) described several new species of helminths from charadriids from King Island, Tasmania, from material gathered for the study recorded here.

The purpose of this study is to examine and compare the helminth parasite community composition and structure among two resident and two migrant waders from King Island. Comments on changes in helminth communities over time and migration are included.

We chose to study these four species of hosts because they were common components of the shorebird community, utilising differing habitats but with possible overlap during foraging, and because nothing was known about helminth communities in Charadriidae from King Island.

MATERIAL AND METHODS

Populations of two species of resident waders, *Charadrius ruficapillus* (N = 20) and *Vanellus miles* (N = 5), and two of migrants, *Arenaria interpres* (N = 20) and *Calidris ferruginea* (N = 5), were collected on King Island, Tasmania, from 26 February to 8 March 1993. Birds were taken under permit, placed immediately in individual plastic bags, refrigerated and examined within six hours. Acanthocephalans, cestodes and trematodes were fixed in alcohol-formalin-acetic acid (AFA), stained in Semichon's

acid carmine or Ehrlich's hematoxylin, cleared in clove oil and mounted in Canada balsam. Nematodes were fixed and preserved in 70% ethanol and examined in temporary lactophenol mounts. Voucher specimens were deposited in the University of Nebraska State Museum, Parasitology Division, Harold W. Manter Laboratory HWML39356 to 39460 and in the Invertebrate Zoology Department, Tasmanian Museum K1679 to 1693.

Two software statistical programs were utilised to analyse the data; NCSS, 329 N. 1000 E., Kaysville, Utah, USA, and Oakleaf Systems, PO Box 472, Decorah, Iowa, USA. The following statistical procedures were used to define the component helminth community (composition and structure) and to compare communities between *C. ruficapillus* and *A. interpres*:

- the Martinez-Inglewicz and D'Agostino Omnibus tests for normalcy;
- two sample t-tests for number of species of helminths (normal data with equal variances);
- Aspen-Welch test for number of helminths (normal data with unequal variances);
- Mann-Whitney-*U* test to test for J' values (non-normal data with equal variances);
- Kruskal-Wallis test for changes in helminth numbers from the same collecting site over time, and number of species of helminths and number of helminths among migratory charadriids;
- variance to mean ratio test (S^2/X with X^2 goodness-of-fit test) for dispersion (uniform-random-contagious) for each species of parasite, and for the number of species of parasites and number of parasites of the population using the total from each host;
- Shannon's index for diversity (Pielou's J'), in which a J' value was calculated for each host and these values were summed and total mean J' values for the populations were derived (the closer the J' values were to 1.00, the more evenly the helminths were distributed among the hosts);
- Morisita's index of similarity, Jaccard's coefficient of similarity and percent similarity to evaluate community similarity between the above two species of hosts (the closer the values to 1.00 the greater the similarity);
- X-abundance and graphical analysis (by plotting helminth prevalence [X] versus percent of total [Y] for each species of helminth and observing the position and relationship of individual species to all others) to define the dominant species of helminth communities; and lastly,
- the X^2 statistic with Cole's coefficient and Spearman's rank correlation coefficient for interspecific association analysis.

Infracommunity composition and structure of helminths was examined by dividing the gastrointestinal tract into the following sections: oral cavity, oesophagus, proventriculus, ventriculus; small intestine into equal thirds beginning from the most anterior, paired caeca, large intestine and cloaca. All other internal organs and the body cavity were also examined. Parasite guilds were investigated using the following classifications proposed by Bush & Holmes (1986) and Bush (1990):

(1) trematode guild — mucosal, feed by engulfing gut tissue and by absorbing nutrients across the body surface;
(2) luminal absorbers — large cestodes and all acanthocephalans, attached to the mucosa but bodies are luminal, feed strictly by absorbing materials across the body surface;
(3) mucosal absorbers — small cestodes intimately associated with the mucosa;
(4) nematode guild — mucosal, feed strictly by engulfing gut tissue or contents.

Helminth specialists and generalists were categorised using the following criteria: specialists — those helminth species that either have the bulk of reproducing adults found only in a single host species or have been reported from a single host species, and generalists — found or reported from several host species, including hosts from other regions (Edwards & Bush 1989, Bush 1990, Hinojos *et al.* 1993). For applicable statistical tests, significance was assumed when P 0.05. Statistical tests of data for parasite communities of *C. ferruginea* and *V. miles* were limited because of small numbers examined. Abbreviations used were: X = mean of the population; SD = standard deviation; M = median of the population; R = range; GI = gastrointestinal; SI = small intestine; T, L, M, N, Tis = respective guilds — trematode, luminal absorber, mucosal absorber, nematode, and tissue other than GI tract.

RESULTS

Red-capped plover *C. ruficapillus* (N = 20)

A total of 1458 helminth parasites (X abundance = 72.9, SD = 60.7, M = 50.0) consisting of 13 species (X = 3.6, SD = 1.1, M = 3.0) was collected from this host. The parasite population in the community was normally distributed ($P < 0.05$), and the parasites were fairly evenly distributed among the hosts (J' = 0.69). The number of species of parasites was also normally distributed ($P < 0.05$) and was uniform in dispersion ($S^2/X = 0.33$, $P < 0.01$). All hosts were infected with at least one species of helminth (R = 1–6 species), and after host #14 only one additional species was observed that had not been observed previously. Among the helminths, eight species of trematodes, four of cestodes and one of acanthocephalans were represented. Two trematodes, *Levinseniella howensis* and *Maritrema eroliae,* and a cestode, *Proterogynotaenia* sp., were the most prevalent and abundant parasites. They accounted for 77.4% of the total number of parasites and were considered the dominant species in the community (table 1). All species of parasites were contagious (clumped or aggregated) with respect to dispersion ($P < 0.01$ for each species). There was a positive association between infections of *L. howensis* and *Proterogynotaenia* sp. (+0.72). A less pronounced association, one positive and one negative, occurred between *L. howensis* and *Hymenolepis lauriei* (+0.57) and between *Proterogynotaenia* sp. and *H. lauriei* (–0.47). Expected frequencies were too small to use the Chi-square statistic for the above associations. Four species of trematodes were new to science and have been described recently; *Maritrema spinosulum, Microphallus pearsoni, M. pseudogonotylus* and *Rhynchostophallus insularegii* (Deblock & Canaris 1996, 1997). The cestode *Proterogynotaenia* sp. is a new species now being described.

Ruddy turnstone *A. interpres* (N = 20)

A total of 3656 helminth parasites (X abundance = 182.8, SD = 156.3, M = 141) consisting of 14 species (X = 5.2, SD = 1.2, M = 5.0) was collected from this host. The parasite population in the community was normally

TABLE 1
Helminths of the red-capped plover *Charadrius ruficapillus*, King Island, Tasmania (N = 20)

Helminths*	Prevalence	Abundance		Range	Total	% of total
	%	mean	SD			
Trematoda						
Acanthoparyphium charadrii Yamaguti, 1939 T	15	1.0	3.38	1–15	19	1.3
Levinseniella howensis Johnston, 1916 T	70	11.9	21.64	2–90	238	16.3
L. monodactyla Deblock and Pearson, 1970 T	15	4.7	14.04	15–60	94	6.5
Maritrema eroliae Yamaguti, 1939 T	60	15.4	34.46	1–136	308	21.1
M. spinosulum Deblock and Canaris, 1996 T	5	0.4	1.79	–	8	0.6
Microphallus pearsoni Deblock and Canaris, 1997 T	20	1.6	4.51	1–17	31	2.1
M. pseudogonotylus Deblock and Canaris, 1997 T	25	1.3	3.34	1–14	26	1.8
Rhynchostophallus insularegii Deblock and Canaris, 1997 T	5	0.2	0.89	–	4	0.3
Cestoidea						
Aploparaksis leonovi Spasskii, 1961 L	5	0.2	0.67	–	3	0.2
Nadejdolepis lauriei (Davies, 1939) M	15	5.6	16.20	15–67	112	7.7
N. mudderbugtenensis (Baer, 1956) M	15	0.6	2.08	1–9	13	0.9
Proterogynotaenia sp. L	85	29.1	39.68	2–149	582	40.0
Acanthocephala						
Plagiorhynchus charadrii Yamaguti, 1939 L	25	0.1	2.97	1–13	20	1.4

* Guilds: T = trematode; L = luminal absorber; M = mucosal absorber.

distributed ($P < 0.05$) and the parasites fairly evenly distributed among the hosts ($J' = 0.69$). The number of species of parasites was also normally distributed ($P < 0.05$) and was uniform in dispersion ($S^2/X = 0.22$, $P < 0.01$). All hosts were infected (R = 3–7 species), and after host #12 no additional species were observed that had not been observed previously. Among the helminths, six species of trematodes, seven of cestodes and one of acanthocephalans were represented. The three most prevalent and abundant helminths were the trematodes *Maritrema eroliae*, and *L. howensis*, and the cestode *Trichocephaloides megalocephala*. They accounted for 76.6% of the total number of parasites and were considered the dominant species in the community (table 2). All species of parasites were contagious with respect to dispersion ($P < 0.01$ for each species except for *Arythmorhynchus tringi*, which was random, $P < 0.05$). No positive or negative associations between species of parasites were detected. Of the four recently described helminths from King Island shorebirds (Deblock & Canaris 1996, 1997), only *M. pearsoni* was observed in this host.

Curlew sandpiper *C. ferruginea* (N = 5)

A total of 154 helminth parasites (X abundance = 30.8, M = 13) consisting of five species (X = 1.8, M = 2) was collected from this host. Four of the five hosts were infected with at least one species of parasite (R = 1–4). Among the helminths, four species of cestodes and one of trematode were represented. The cestode *Nadejdolepis paranitidulans* was the most prevalent and abundant helminth. It accounted for 87.0% of the total number of parasites and was the dominant species (table 3).

Masked lapwing *V. miles* (N = 5)

A total of 282 helminth parasites (X abundance = 56.4, M = 9) consisting of nine species (X = 2.8, M = 3) was collected from this host. All five of the hosts were infected with at least one species of parasite (R = 1–4). Among the helminths, four species of cestodes, two of nematodes, one of trematode and two of acanthocephalans were represented. The cestode *N. lauriei* and the nematode *Porrocaecum heteroura* were the most prevalent. The cestode *Anomotaenia microrhyncha* was the most abundant, accounting for 82.6% of the total number of parasites, and was the dominant species (table 4).

Parasite guilds

The trematode guild was predominant in the resident red-capped plover *C. ruficapillus* with eight species and 50% of the helminth abundance. A luminal absorber, the cestode *Proterogynotaenia* sp., was very high in prevalence (85%) and abundance (40%) (table 1). The trematode guild was also predominant in the migratory ruddy turnstone, *A. interpres*, with six species and 67.2% abundance. One luminal absorber, the cestode *T. megalocephala*, was also very prevalent (95%) and abundant (22%) (table 2).

Mucosal absorbers were predominant in the small sample of migrant curlew sandpipers, *C. ferruginea*, with the cestode *N. paranitidulans* being the most prevalent (60%) and abundant (83%) (table 3). Luminal absorbers were the predominant guild in the resident masked lapwing *V. miles*. This was the only species of host that showed a mix of both terrestrial and marine-associated helminths and harboured the nematode guild.

TABLE 2
Helminths of the ruddy turnstone *Arenaria interpres*, King Island, Tasmania (N = 20)

Helminths*	Prevalence %	Abundance mean	Abundance SD	Range	Total	% of total
Trematoda						
Echinostephilla virgula Lebour, 1909 T	45	2.1	3.75	1–15	42	1.2
Gynaecotyla macrocotylata Smith, 1983 T	25	7.9	19.28	1–77	158	4.3
Levinseniella howensis T	100	16.4	19.44	1–66	328	9.0
L. monodactyla T	15	0.5	1.23	2–5	9	0.3
Maritrema eroliae T	70	88.4	105.34	2–355	1767	48.3
Microphallus pearsoni T	15	7.6	13.15	3–46	151	4.1
Cestoidea						
Anomotaenia skrjabini Ginetsinskaya and Naumov, 1958 L	40	5.1	8.97	1–28	101	2.6
A. clavigera (Krabbe, 1869) L	15	6.0	17.44	0–73	119	3.3
Aploparaksis leonovi L	25	1.5	3.19	2–10	30	0.8
Dicranotaenia amphitricha (Rudolphi, 1819) M	5	0.4	1.57	–	7	0.2
Nadejdolepis nitidulans (Krabbe, 1882) M	35	7.6	26.18	2–118	152	4.2
Ophryocotyle proteus Friis, 1870 M	10	0.7	2.06	5–8	13	0.4
Trichocephaloides megalocephala (Krabbe, 1869) L	95	38.9	44.04	1–150	778	21.3
Acanthocephala						
Arythmorhynchus tringi Gubanov, 1952 L	5	0.1	0.22	–	1	0.03

* Guilds as table 1.

TABLE 3
Helminths of the curlew sandpiper *Calidris ferruginea*, King Island, Tasmania (N = 5)

Helminths*	Prevalence (no. infected)	Mean abundance	Range	Total	% of total
Trematoda					
Acanthoparyphium charadrii T	2	1.6	3–5	8	5.2
Cestoidea					
Anomotaenia microrhyncha L	1	0.2	–	1	0.7
Echinocotyle dubininae M	1	0.4	–	2	1.3
Nadejdolepis paranitidulans (Golikova, 1959) M	3	26.8	11–62	134	87.0
Ophryocotyle proteus M	2	1.8	3–6	9	5.8

* Guilds as table 1.

TABLE 4
Helminths of the masked lapwing Vanellus miles from King Island, Tasmania (n = 5)

Helminths*	Prevalence (no. infected)	Mean abundance	Range	Total	% of total
Trematoda					
Brachylaima fuscatum Rudolphi, 1819 T	1	4.2	–	21	7.5
Acanthoparyphium charadrii T	1	0.6	–	3	1.1
Cestoidea					
Anomotaenia microrhyncha Krabbe, 1869 L	2	46.6	6–227	233	82.6
Chitinorecta agnosta Megitt, 1927 M	1	0.2	–	1	0.4
Nadejdolepis lauriei M	3	2.4	3–6	12	4.3
Nematoda					
Heterakis sp. N	1	0.2	–	1	0.4
Porrocaecum heteroura Creplin, 1829 N	3	1.4	2–3	7	2.5
Acanthocephala					
Plagiorhynchus gracilis Petrochenko, 1958 L	1	0.4	–	2	0.7
Plagiorhynchus sp. L	1	0.4	–	2	0.7

* Guilds as table 1; N = nematode.

Host specialists and generalists

The total helminth pool consisted of 28 species, and at least 25 were generalists, in that all have been reported from other birds. Two trematodes, *M. pseudogonotylus* and *R. insularegii,* and the cestode *Proterogynotaenia* sp. may be specialists in *C. ruficapillus* but we do not know enough about host–parasite relationships and geographic distribution in Tasmania to categorise them. Eight helminth species were recovered from at least two species of host, and *Acanthoparyphium charadrii* infected three species of host. The largest number of shared species came from the trematode guild, and there were none from the nematode guild (table 5). The life cycles of at least 19 species of helminths were occurring in their entirety on King Island, because all infections in resident hosts were the result of ingesting infected food items from the local habitat. Life cycles of microphallids, which are short-lived as adults, may also be occurring locally. For example, the microphallid *L. howensis* was observed emerging from the metacercarial cysts harboured by gammarids ingested by *A. interpres.*

Infracommunity

Most species of helminths were in largest numbers in a specific section of the GI tract. The largest number of helminths was recovered from the anterior third of the small intestine in *C. ruficapillus* and the middle third in *A. interpres* (fig. 1). The paired caeca in both species of host were the site of choice for the trematode *L. howensis.* In both *C. ruficapillus* and *A. interpres,* the three dominant species of helminths, in general, were in greatest abundance in different sections of the GI tract. This was most evident for the two species of cestodes and the trematode *L. howensis* (figs 2, 3). We could not determine if any particular section was saturated (packed), although some species did extend in smaller numbers into adjacent sections of the small intestine. Most parasites recovered from the large intestine and cloaca were unhealthy in appearance or moribund.

Community comparison, *C. ruficapillus* vs *A. interpres*

There were five species of helminths which infected both species of host with a similarity of 32.7% (Morisita's index = 0.44; Jaccard's coefficient = 0.23). The mean number of species and mean number of helminths were significantly higher in *A. interpres* ($P < 0.00001$ and $P < 0.01$ respectively). Evenness of distribution of parasites for the two species of hosts was not very different ($J' = 0.69$ vs 0.69; $P > 0.06$). Over a five-day period, helminth numbers increased significantly for the combined three dominant species *L. howensis, M. eroliae* and *T. megalocephala* in *A. interpres* ($P < 0.001$), but not overall, and helminths decreased significantly overall for *C. ruficapillus* ($P < 0.05$).

DISCUSSION

Helminth Regional Relationships

The pool of helminth parasites on King Island infecting charadriids is well established and, as indicated by infections in the non-migratory host species, many of the life cycles occur in the area. Two species of the helminths observed in our study, *Gynaecotyla macrocotylata* and *M. eroliae,* were reported from southern Tasmania by Smith (1983). He also described three species of microphallid trematodes from the same general locality: *Atriophallophorus coxiellae* from *Charadrius cucullatus* Vieillot and *C. ruficapillus*; *Maritrema calvertensis* from *C. cucullatus* and *Charadrius melanops* Vieillot; and *Microphallus tasmaniae* from *C. cucullatus, C. melanops* and *C. ruficapillus* (Smith 1974). None of these three parasites was observed in our study. Three species of microphallids observed in our study have been reported or described from shorebirds on or near the Australian mainland, *Maritrema eroliae* in *C. mongollus* Pallas and *Calidris acuminata* Horsefield from Queensland (Deblock & Pearson 1968, Deblock & Canaris 1996), and *Levinseniella monodactyla* in *Charadrius mongollus* from Queensland (Deblock & Pearson 1970) and *L. howensis* in *Pluvialis*

TABLE 5
Abundance of shared helminths among four species of shorebirds, King Island, Tasmania

Helminths*	*Charadrius ruficapillu*	*Arenaria interpres*	*Calidris ferruginea*	*Vanellus miles*
Acanthoparyphium charadrii T	1.0	–	1.6	0.6
Levinseniella howensis T	11.9	16.4	–	–
L. monodactyla T	4.7	0.5	–	–
Maritrema eroliae T	15.4	88.4	–	–
Microphallus pearsoni T	1.6	7.6	–	–
Anomotaenia microrhyncha L	–	–	0.2	46.6
Aploparaksis leonovi L	0.2	1.5	–	–
Nadejdolepis lauriei M	5.6	–	–	2.4

* Guilds as table 1.

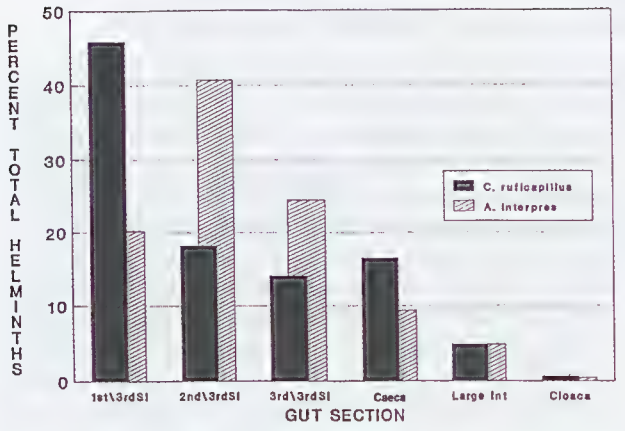


FIG. 1 — Distribution of helminths in the gastrointestinal tract of Charadrius ruficapillus *and* Arenaria interpres, *King Island, Tasmania*

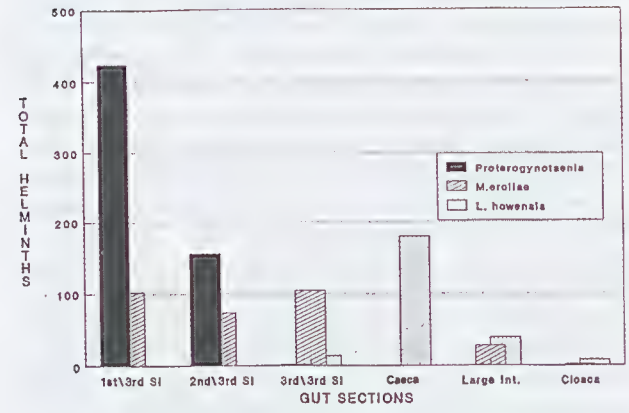


FIG. 2 — Distribution of three dominant helminth species in the gastrointestinal tract of Charadrius ruficapillus, *King Island, Tasmania*

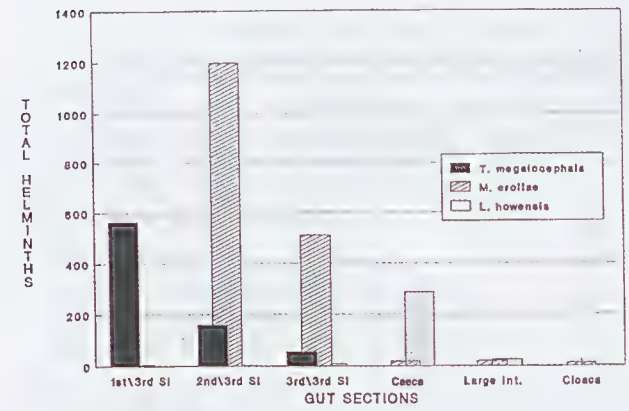


FIG. 3 — Distribution of three dominant helminth species in the gastrointestinal tract of Arenaria interpres, *King Island, Tasmania*

dominica Müller from Lord Howe Island (Pearson & Deblock 1979). Microphallids are predominantly marine and short-lived, and appear to be mostly regional. It is unlikely any of the Australian and Tasmanian species will be found in other regions. One exception may be *M. eroliae* but, according to Deblock & Canaris (1992, 1996), it appears to be a species-complex. Mawson (1968) reported nematodes from 20 species of waders, mostly from South Australia, but none of these parasites was observed in our study. All other helminth species reported here, except for the five new species, have been described or reported from charadriids or related species from other continents (Eurasia, North and South Americas).

Helminth Distributions and Relationships

Contagious (clumped) distributions of helminths as observed in *A. interpres* and *C. ruficapillus* appear to be typical for shorebirds. A summary of possible causes for contagious distribution gleaned from literature by Secord & Canaris (1993) are as follows: genetic variability within the host population, host susceptibility, host behavioural and social traits, individual feeding habits, spatial location of helminths and intermediate hosts, and chance distribution of infective stages. The strong positive relationship between the trematode *L. howensis* and the cestode *Proterogynotaenia* in *C. ruficapillus* may be the result of both parasites utilising the same intermediate host. The other two helminth relationships in this host, one positive and one negative, are not very strong and may be influenced by sample size.

Helminth Community Changes

Parasite communities in shorebirds may change over time. This appeared to be happening during the relatively short period of this study. Increase in helminths in *A. interpres* during the latter part of the study was coincidental with ingestion of gammarids infected with metacercariae of *L. howensis* and with enhanced fat deposits in preparation for migration. Both observations of increase of helminths in *A. interpres* and decrease in the resident *C. ruficapillus* need to be studied over a longer time-period with increased sample size before we consider these observations definitive.

Ginetsinskaya (1953) compiled data from 12 shorebird–helminth studies (N = 1539 birds) done in various regions of the USSR. Based on the number of hosts infected with the four major helminth groups, trematodes, cestodes, nematodes and acanthocephalans, she concluded cestodes were predominant in ten of the 12 studies. Trematodes were predominant in two, both from the maritime littoral zone, and most species of acanthocephalans observed were also from this zone. She also stated that the number of worm species, both overall and within each helminth group, was markedly higher on the nesting grounds than in migrating birds. She attributed the loss of parasites in migration to a seasonal decrease in invertebrates, which act as intermediate hosts, and losses of short-lived parasites, particularly trematodes. Bush (1990) examined willets, *Catoptrophorus semipalmatus* Gmelin, from nesting grounds (freshwater) in Canada and wintering grounds (marine) in the USA and reported no significant difference in number of species of helminths but a significantly higher number

TABLE 6
Summary of selected data from 17 shorebird studies

Host*	Species richness	Mean abundance	Most abundant group–% of total	Guilds present†	Locality	Reference
(1) Western sandpiper-Mig (*Calidris mauri*) N = 50, autumn–spring, freshwater	5	1.1	cestode–77.4	T-1,L-4	SW Texas	Canaris & Munir 1991
(2) Greater yellowlegs-Mig (*Tringa melanoleuca*) N = 48, autumn–spring, freshwater	9	25.9	cestode–82.3	T-3, L-2, M-2, TisT-2	SW Texas	Secord & Canaris 1993
(3) Wilson's phalarope-Mig (*Phalaropus tricolor*) N = 100, autumn–spring, freshwater	12	8.3	cestode–63.5	T-5, L-4, M-1, TisT-2	SW Texas	Yanez & Canaris 1988
(4) Common snipe-Mig (*Capella gallinago*) N = 60, autumn–spring, freshwater	14	12..2	nematode–46.1	T-3, L-8, N-3	SW Texas	Leyva *et al.* 1980
(5) Dunlin-W (*Calidris alpina*)						
A. N = 28, Oct.–Apr., marine	26	254.2	cestode–50.2	T-8, L-9, M-5, N-3, TisN-1	Ireland	Cabot 1969
B. N = 27, Feb. & Mar., marine	17	291.3	cestode–97.0	T-6, L-8, M-2, N-1	California	Ching 1990
(6) Willet 37 (*Catoptrophorus semipalmatus*)						
A. N = 46, June, freshwater-Nes	3	62.3	cestode–59.2	T-14, L-12, M-9, N-2	Alberta, Manitoba	Bush 1990
B. N = 9, Jan., marine-W	11	618.2	trematode–99.0	T-7, L-2, 2?	California	Ching 1990
C. N = 30, Jan.–Feb., marine-W	34	723.3	trematode–91.3	T-22, L-6, M-3,N-3	Florida, Louisiana	Bush 1990
(7) American avocet (*Recurvirostra americana*)						
A. N = 22, May–June, freshwater-Nes	41	3,727	cestode–92.5	T-8, L-10, M-17,N-5, TisT-1	Alberta, Manitoba	Edwards & Bush 1989
B. N = 33, autumn-spring, freshwater-MN	19	220.2	cestode–88.8	T-8, L-3, M-2, N-2, TisT-3	SW Texas	Garcia & Canaris 1987
C. N = 60, July–Sep., freshwater-Nes	6	79.5	cestode–91.6	L-4, M-1, TisT-1	Utah	Hinojos *et al.* 1993
(8) Black-necked stilt-MN (*Himantopus mexicanus*) N = 35, autumn–spring, freshwater	19	162	cestode–83.2	T-3,L-4, M-3, N-6, TisN-1, TisT-2	SW Texas	Hinojos & Canaris 1988
(9) Long-billed curlew-Nes (*Numenius americana*) N = 18, June, freshwater	9	318	cestode–99.0	T-1, L-8	Alberta	Goater & Bush 1988
(10) Ruddy turnstone (*Arenaria interpres*)						
A. N = 6, Oct.–Apr., marine-W	11	172.3	cestode–50.0	T-4, L-4, M-1, N-1, TisT-1	Ireland	Cabot 1969
B. N = 20, Feb.–Mar., marine-W	14	182.8	trematode–67.2	T-6, L-5, M-3	Tasmania	This study
(11) Red-capped plover (*Charadrius ruficapillus*) N = 20, Feb.–Mar., marine, resident	13	72.9	trematode–49.9	T-8, L-3, M-2	Tasmania	This study

* Mig = migrating; W = wintering; Nes = nesting; MN = mostly migrating, but some nesting occurs in the area.
† Guilds as before; Tis = tissue.

of helminths on the wintering grounds. Cestodes were in highest abundance on the nesting grounds and trematodes on wintering grounds (table 6).

OBSERVATIONS

We compiled data from 17 studies, including this one, on 11 species of shorebirds (N = 612) from both freshwater and marine habitats (table 6). Cestodes were the most abundant in all 12 freshwater habitats, trematodes in four marine habitats, and nematodes in one, the more terrestrial common snipe *Gallinago gallinago* Linnaeus. Trematode and luminal guilds were represented by the largest numbers of occurrences (107 and 96 respectively) followed by mucosal guilds (51), and nematodes (26). We added a tissue guild (= Tis) for helminths occupying others organs or cavities. However, not all of the above studies include this guild. We also placed hosts in one of four groups. With respect to mean number of species the results were 23 nesting birds, 10 migrating, 19 migrating with some nesting and 19 wintering. Although there was no significant difference ($P > 0.05$), the same observation reported by Ginetsinskaya (1953) of migrating shorebirds having the fewest species is also attendant in our data. We also examined mean abundances as above with the following results; 1122, 12, 191 and 374. There was a significant difference ($P < 0.05$) with the migrating shorebirds having the fewest helminths. We present these observations with caution, because each migrant species needs to be examined throughout its range before we can be sure about the dynamics of helminth communities under these differing biotic and abiotic circumstances.

We assume that additional studies of helminth communities of waders from Tasmania would reveal new species, because of geographic isolation, availability of non-migrating charadriids as hosts and the established presence of helminths whose adult stages are short-lived, as in the Microphallidae. Finally, we expect additional commonality of helminths among species of hosts in Tasmania and Australia and, because many species of charadriids migrate to and from this region, additional affinity of some helminths with charadriids from other continents.

AKNOWLEDGEMENTS

We wish to thank Jamie Bayly-Stark, Assistant Director Wildlife, David Rounsevell, Wildlife Research Officer, Dr Steven Smith, Chief Zoologist, Department of Parks, Wildlife and Heritage, Tasmania, and Dr Michael Stoddart, formerly Professor of Zoology, University of Tasmania, for their very helpful suggestions, support and friendly courtesy. AGC especially wishes to thank Nigel Burgess, King Island, for his knowledge, support beyond the call of duty and a lasting friendship.

REFERENCES

Bush, A.O., 1990: Helminth communities in avian hosts: determinate of pattern. *In* Esch, G.W., Bush, A.O. & Aho, J.M. (Eds): *PARASITE COMMUNITIES: PATTERNS AND PROCESS.* Chapman and Hall, New York: ch. 8.

Bush, A.O. & Holmes, J.C., 1986: Intestinal helminths of lesser scaup ducks: an interactive community. *Can. J. Zool.* 64: 142–152.

Cabot, D., 1969: Helminth parasites from Charadriiform birds at Galway Bay, Co. Galway. *Proc. R.I.A.* 68: 149–159.

Canaris, A.G. & Munir, N.T., 1991: Helminth parasites of the western sandpiper, *Calidris mauri* (Aves), from El Paso and Hudspeth counties, Texas. *J. Parasitol.* 77: 787–789.

Ching, H.L., 1990: Some helminth parasites of dunlin (*Calidris alpina*) and western willet (*Catoptrophorus semipalmatus*) from California. *J. Helminthol. Soc. Wash.* 57: 44–50.

Deblock, S. & Canaris, A.G., 1992: Contribution a l'étude des Microphallidae Travassos, 1920 (Trematoda) XLIII. - De six espèces d'Afrique du Sud dont une d'un genre nouveau. *Ann. Par. Hum. Comp.* 67: 204–218.

Deblock S. & Canaris, A.G., 1996: Microphallidae, Trematoda: XLVIII. - Quatre Maritrema de group eroliae parasites d'oiseaux Australiens. *Parasite* 4: 357–361.

Deblock S. & Canaris, A.G., 1997: Contribution a l'étude des Microphallidae (Trematoda). XLIX. Espèces d'oiseaux de Tasmanie. Création de *Rhyncostophallus* n. g. *Systematic Parasitol.* 37: 13–19.

Deblock, S. & Pearson, J. C., 1968: Contribution a l'étude des Microphallidés Travassos, 1920 (Trematoda) XV. De quelques espèces d'Australie dont *Pseudospelotrema anenteron* n. sp. *Ann. Par. Hum. Comp.* 43: 457–465.

Deblock, S. & Pearson, J.C., 1970: Contribution a l'étude des Microphallidés Travassos, 1920 (Trematoda) XXII. De deux *Levinseniella* d'Australie dont un nouveau: *Lev.* (*Monarrhenos*) *monodactyla*. Essai de clé diagnostique des espèces du genre. *Ann. Par. Hum. Comp.* 45: 773–791.

Edwards, D.D. & Bush, A.O., 1989: Helminth communities in avocets: Importance of the compound community. *J. Parasitol.* 75: 225–238.

Esch, G.W., Gibbons, J.W. & Bourque, J.E., 1975: An analysis of the relationship between stress and parasitism. *Am. Mid. Nat.* 93: 339–353.

Friend, M., 1992: Environmental influences on major waterfowl diseases. *Trans. 57th N. Am. Wildlf. and Nat. Res. Conf.* 56: 517–525.

Garcia, C.A. & Canaris, A.G., 1987: Metazoan parasites of *Recurvirostra americana* Gmelin (Aves), from southwestern Texas and Monte Vista National Wildlife Refuge, Colorado, with a checklist of helminth parasites from North America. *SW Nat.* 32: 85–91.

Ginetsinskaya, T.A., 1953: Helminthofauna of migratory shore birds of Volga Delta. *In* Petrov, A. M. (Ed.): *CONTRIBUTIONS TO HELMINTHOLOGY. Izdatel'stova Akademii Nauk SSSR Moskva. Israel Program for Sci. Trans.* 1966: 147–156.

Goater, C.P. & Bush, A.O., 1988: Intestinal helminth communities in long-billed curlews: the importance of cogeneric host-specialists. *Holarctic Ecol.* 11: 140–145.

Green, R.H., 1989: *BIRDS OF TASMANIA, AN ANNOTATED CHECKLIST WITH ILLUSTRATIONS.* Potoroo Publishing, Launceston

Hayman, P., Marchant, J. & Prater, T., 1986: *SHOREBIRDS, AN IDENTIFICATION GUIDE.* Houghton Mifflin Company, Boston.

Hinojos, J.G. & Canaris, A.G., 1988: Metazoan parasites of *Himantopus mexicanus* Müller (Aves) from southwestern Texas, with a checklist of helminth parasites from North America. *J. Parasitol.* 74: 326–331.

HINOJOS, J.G. CAMPBELL, B.K. & CANARIS, A.G., 1993: Helminth parasites of the American avocet *Recurvirostra americana* (Aves), from the Salt Lake Basin, Utah. *J. Parasitol.* 79: 114–116.

LEYVA, T., CANARIS, A.G. & BRISTOL, J.R., 1980: Helminths and ectoparasites of the common snipe (*Capella gallinago*) from South West Texas and Monte Vista National Wildlife Refuge, Colorado. *J. Wildl. Dis.* 16: 549–557.

MAWSON, P.M., 1968: Nematodes from Australian waders. *Parasitology* 58: 277–305.

PEARSON, J. C. & DEBLOCK, S., 1979: Contribution a l'étude des Microphallidés Travassos, 1920 (Trematoda) XXXIV. Redescription de *Levinseniella howensis* Johnston, 1917. *Ann. Par. Hum. Comp.* 54: 31–37.

SCHULZ, M., 1990: Notes on the waders of Flinders and King Islands, Bass Straight. *Stilt* 17: 40–43.

SECORD, M.L. & CANARIS, A.G., 1993: The metazoan parasite community of migrating greater yellowlegs, *Tringa melanoleuca* from the Rio Grande Valley, Texas and New Mexico. *J. Parasitol.* 79: 690–694.

SLATER, P., SLATER, P. & SLATER, R., 1989: *THE SLATER FIELD GUIDE TO AUSTRALIAN BIRDS.* The Griffen Press, Adelaide.

SMITH, S.J., 1974: Three new microphallid trematodes from Tasmanian birds. *Pap. Proc. R. Soc. Tas.* 107: 197–205.

SMITH, S.J., 1983: Three new species and a new record of microphallid trematodes from Tasmania, with observations on their *In Vitro* development. *Pap. Proc. R. Soc. Tas.* 117: 105–123.

YANEZ, D.M. & CANARIS, A.G., 1988: Metazoan parasite community composition and structure of migrating Wilson's phalarope, *Steganopus tricolor* Vieillot, 1819 (Aves), from El Paso, county Texas. *J. Parasitol.* 74: 745–762.

(accepted 24 June 1998)

CUNOMYIA, A DISTINCTIVE NEW HILARINE FLY GENUS FROM THE TASMANIAN WORLD HERITAGE AREA (DIPTERA: EMPIDIDAE)

by Daniel J. Bickel

(with two text figures)

BICKEL, DANIEL J., 1998 (31:xii): *Cunomyia*, a distinctive new hilarine fly genus from the Tasmanian World Heritage Area (Diptera: Empididae). *Pap. Proc. R. Soc. Tasm.* 132: 59–63. ISSN 0080–4703. Entomology Section, Australian Museum, 6 College Street, Sydney South, NSW, Australia 2000.

Cunomyia unica gen. & sp. nov. (Diptera: Empididae: Empidinae: Hilarini) is described from sites in western Tasmania. This monotypic genus is distinguished from other genera in the tribe Hilarini by the following combination of characters: vein R_{4+5} unbranched, Sc incomplete, terga 7 and 8 not reduced or modified, so that the hypopygium is positioned upright at end of abdomen, not lying forward, and the male cercus divided into a cercal plate and digitiform clasping section. *Cunomyia* is considered primitive with respect to other Hilarini, on the basis of its clasping cercus and postabdominal structure.

Keywords: *Cunomyia*, Diptera, Empididae, Hilarini, morphology, Tasmania.

INTRODUCTION

Throughout the world, flies of the tribe Hilarini (Diptera: Empididae: Empidinae) can be seen flying back and forth above the surface of ponds, lakes and streams. This low, cruising flight is a type of aerial swarming conducted by males to attract mates. Morphologically, the most readily observable character of the Hilarini is the enlarged basitarsus on the male foreleg, which produces silk for wrapping prey or debris to present as "nuptial gifts" to females (Eltringham 1928).

The Tasmanian Hilarini are poorly known, with only 11 described species. Nine of these were described in White's 1916 paper, a work that currently serves as the basic taxonomic reference for the *entire* Australian fauna (White 1917). However, the Tasmanian fauna, like that of other southern temperate regions, is very rich, and more than 100 species have been separated from collections. These will be treated in future revisions of the entire Australian fauna (also see Bickel 1996).

The present paper describes a distinctive new hilarine genus, *Cunomyia*, from montane sites in western Tasmania, almost all of which are in the Tasmanian World Heritage Area.

MATERIALS AND METHODS

Morphological terminology follows McAlpine (1981) except for that of the male terminalia, which is based on Cumming *et al.* (1995). Measurements are in millimetres and were made on representative dry specimens. The position of features on elongate structures, such as leg segments, is given as a fraction of the total length, starting from the base. The relative lengths of the podomeres are representative ratios and not measurements, and are presented in the following formula and punctuation: trochanter + femur; tibia; tarsomere 1/ 2/ 3/ 4/ 5.

The following abbreviations and terms are used: MSSC – Male secondary sexual character(s), the non-genitalic characters found only on male body; I, II, III – pro-, meso-, metathoracic legs; C – coxa; T – tibia; F – femur; ac – acrostichal setae; ad – anterodorsal; av – anteroventral; dc – dorsocentral setae; dv – dorsoventral; pd – posterodorsal; pv – posteroventral; t – tarsus; t_{1-5} – tarsomeres 1 to 5. Institutional abbreviations are as follows: Australian Museum, Sydney (AMS); Australian National Insect Collection, CSIRO, Canberra (ANIC); Illinois Natural History Survey, Urbana, Illinois (INHS); Museum of Victoria, Melbourne (MVM).

Genus *Cunomyia* gen. n.

Etymology

Cunomyia is a combination of the Latin "cuna", meaning cradle, and "myia", Greek for fly, referring to the type locality in Cradle Valley, Tasmania. The gender is feminine.

Type species

Cunomyia unica sp. n. (fig. 1).

Diagnosis

Rather large, black flies; body length 7.0–8.0 mm.

Head: ocellar triangle on raised spheroidal mound totally separating vertex from frons; frons narrower than ocellar triangle, with 7–8 short hairs along lateral margins; palp straight and strap-like; scape and pedicel setose (fig. 2A); first flagellomere conical, tapering, with short 2-articulated apical style, but without apical spine.

Thorax: mesonotum anteriad of posterior slope covered with field of uniform short setae obscuring the distinction between setal rows, except for the 3–4 longer posterior dc setae bordering mesonotal depression; laterotergite bare of setae; scutellum with 4–5 pairs of marginal setae.

Legs: TI with anteroapical comb of 8–10 short, even setae; male It_1 distinctly swollen with dense ventral vestiture (MSSC); FII and FIII with anterior, av, and posterior subapical setae.

Wing: broad with well-developed anal lobe; costa circumambient, although narrowing markedly past vein M_1 at wing apex, and reduced in thickness along posterior

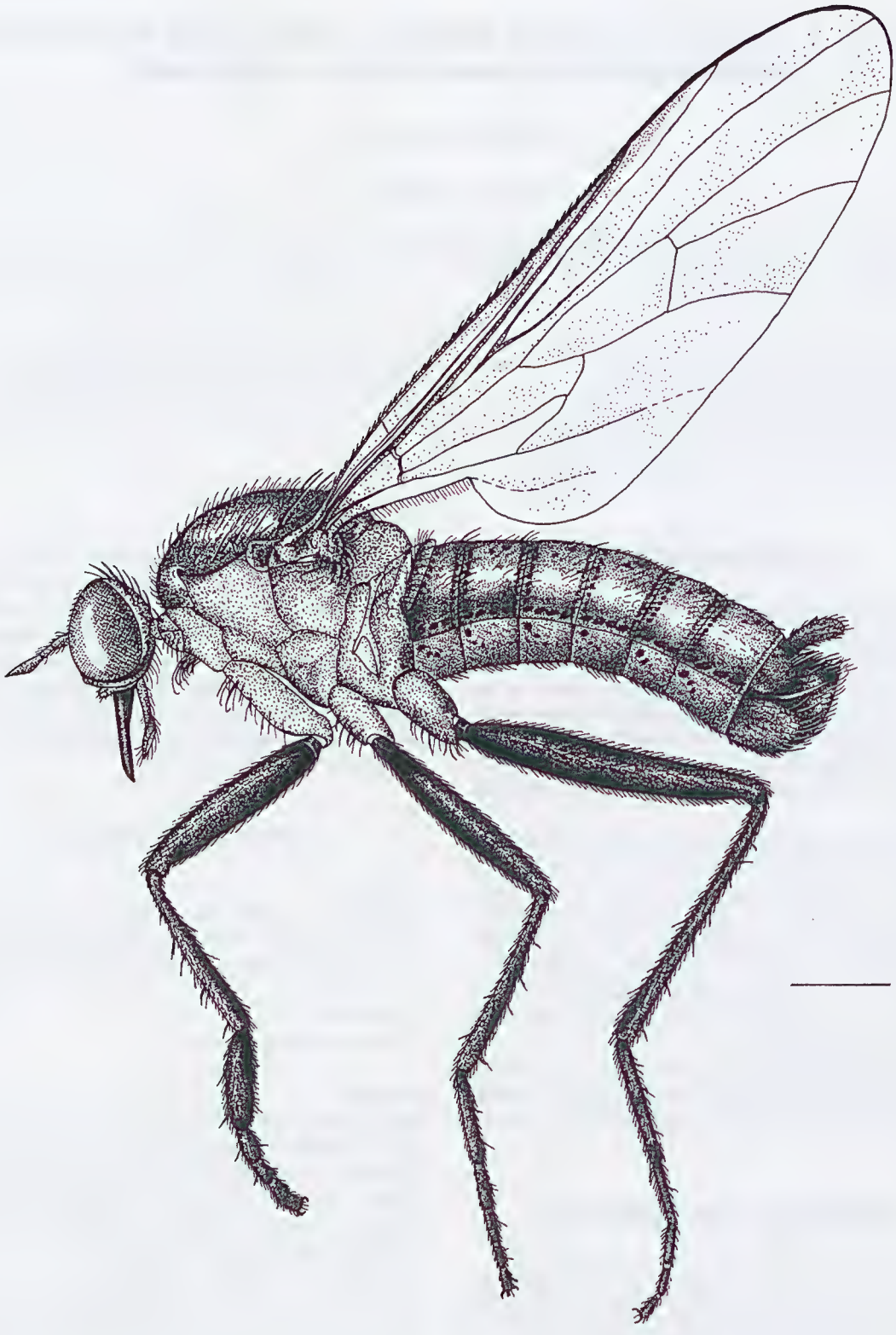


FIG. 1 — Cunomyia unica, *male, habitus. Scale line = 1.0 mm.*

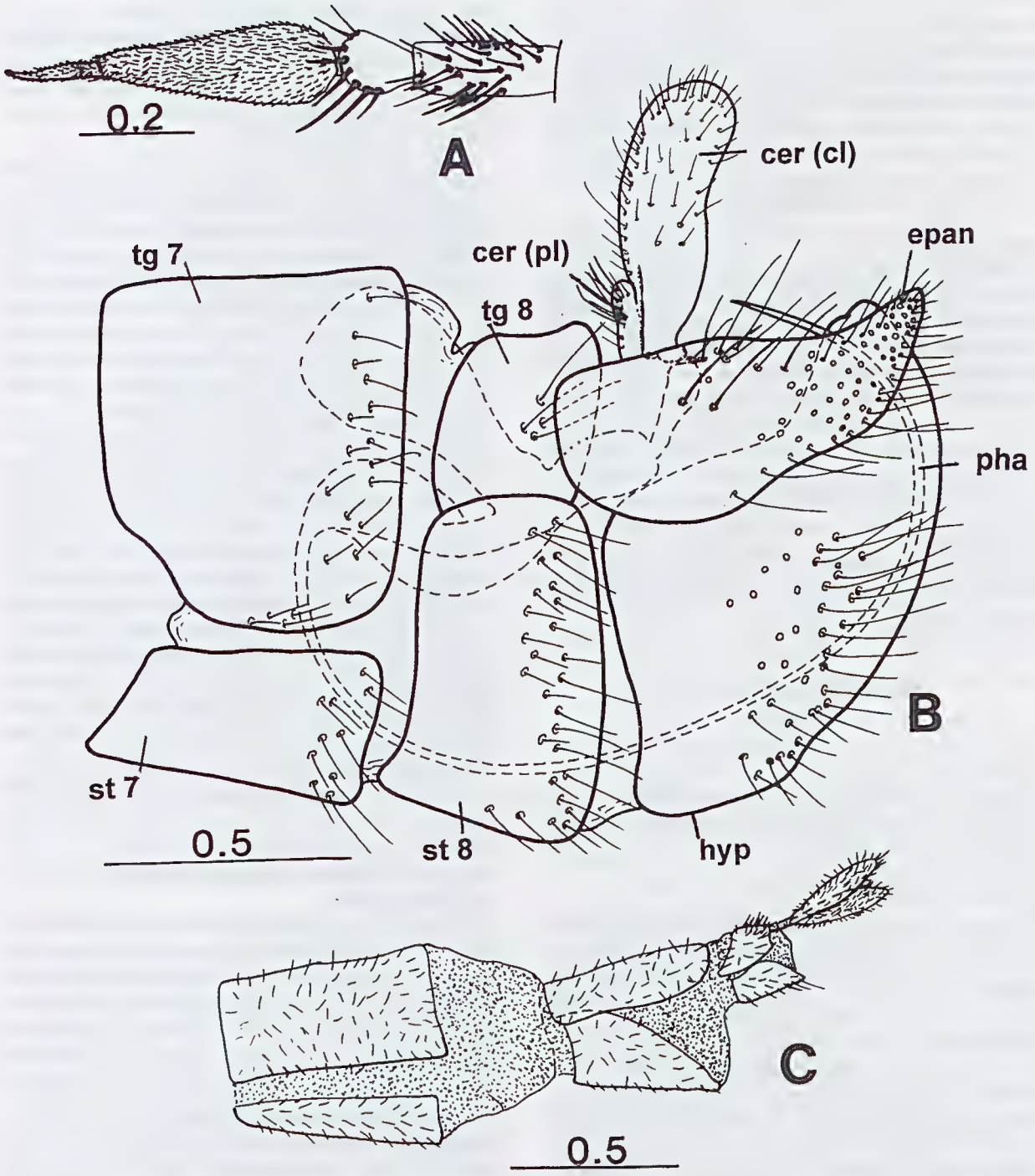


FIG. 2 — Cunomyia unica*: (A) male antenna, left lateral. (B) hypopygium, left lateral. (C) female oviscapt, left lateral. Legend: cer (cl) - clasping cercus; cer (pl) - cercal plate; epan - epandrium; pha - phallus; tg - tergum; st - sternum.*

wing margin; Sc incomplete; R_1 distally swollen near join with costa; R_{4+5} unbranched; CuA_2, which closes cell cup, strongly recurrent.

Abdomen: both terga 7 and 8 well developed, so that hypopygium positioned upright at end of abdomen, not flexed forward (fig. 2B); sternum 8 not ventrally supporting hypopygium; male cercus divided into short basal cercal plate and digitiform clasping cercus; hypandrium keel-like; phallus elongate and conforming to hypandrium; abdomen telescoping; oviscapt relatively unmodified, with well-developed terga and sterna on segments 8–10, and with apical blade-like cerci (fig. 2C).

Remarks

Cunomyia is a monotypic genus known only from Tasmania. It possesses the following characters, which clearly place it in the tribe Hilarini (Bickel 1996): laterotergite bare, tibia I with anteroapical comb of 8–10 short setae, male basitarsus I enlarged or swollen, hypandrium forming a curved convex hood over the phallus, costa circumambient, but reduced in thickness along posterior margin, vein R_1 distinctly swollen before it joins the costa.

Cunomyia is distinguished from other hilarine genera by the following combination of characters: vein R_{4+5} unbranched, Sc incomplete, terga 7 and 8 not reduced or

modified, so that hypopygium is positioned upright at end of abdomen, not lying forward, and male cercus divided into short basal plate and a longer digitiform clasping section. The morphological and phylogenetic significance of the unmodified abdominal terga and the divided cercus will be discussed below. However, it should be noted that *Cunomyia* is distinctive and somewhat isolated within the Hilarini. Its relationships are unclear and, although it is only known from Tasmania, it is not necessarily most closely related to other Gondwanan taxa.

Two other genera in the Hilarini also have R_{4+5} unbranched:

(1) *Atrichopleura* Bezzi includes described species from South Africa, South America, New Zealand (although both Collin [1933] and Smith [1969] suggested that the two New Zealand species might represent a distinct genus), and undescribed species from Australia. Many Australian species have a short and somewhat curved proboscis. *Atrichopleura* has well defined ac and dc setae and a hypopygium flexed over the postabdomen, so that both terga 7 and 8 are somewhat reduced in size. By comparison, *Cunomyia* has a large field of short, undifferentiated thoracic setae and an erect hypopygium, with unmodified terga 7 and 8.

(2) *Hybomyia* Plant is known from a single New Zealand species. In this genus, both veins R_{4+5} and M are unbranched. As well, the proboscis is short and the thorax has well-defined ac and dc setae (Plant 1995).

Cunomyia unica sp. n. (figs 1, 2)

Type material

Holotype, ♂, paratypes, ♂, ♀; Tasmania: Cradle Valley, 13.i.1923, A. Tonnoir; Paratypes, ♂, same but 10.i.1923; ♀, same but 23.i.1923 (ANIC).

Additional material

Tasmania: 31 ♂, 6 ♀, 11 km WSW of Daisy Dell, Cradle Mt–Lake St Clair Natl Park, 950 m, malaise trap, 1–8.i.1992 (INHS); ♂, Pelion Hut, 3 km S of Mt Oakleigh, 41.50'S 146.03'E, 860 m. 30.xi.1990–8.i.1991, malaise trap; ♂, 21 km S of Wilmot, 650 m, 30.i.1967; ♂, Hartz Mountains, 9.xii.1922; 3 ♂, Mt Field Natl Park, 18–21.xii.1922, 21.i.1949; ♂, Mt Field Natl Park, Lake Dobson, 22.i.1948 (ANIC); 2 ♂, 2 ♀, Mt Field Natl Park, Wombat Moor, 42.41'S 146.37'E, 1090 m, alpine herbfield, 25.i.1989, yellow pans; ♂, Pencil Pine Ck, N of Cradle Mt, 41.38'S 145.54'E, 800 m, montane forest, 30.i.1989, yellow pans; ♂, Hanson Peak, nr Cradle Mt, 1200 m, 30.i.1989, alpine herbfield (AMS); 3 ♂, Hastings Caves, Hot Springs Ck, 14.xi.1972, at light (MVM).

Description

Male: length: 7.0–7.8; wing: 5.7–6.0 x 2.3 (fig. 1); large black empidid flies, with black setae unless otherwise noted; characters noted in generic description are not repeated.

Head: spheroidal, with convex post-cranium; post-cranium, vertex, frons, and face brown-black with some grey pruinosity; dorsal and ventral post-occiput covered with short setae; distinct row of postorbitals evident, culminating in 3–4 pairs of stronger postvertical setae; ocellar triangle with pair of long diverging ocellar setae anteriad of lateral ocelli; slightly notched laterad of antennae; face as wide as frons; palp black and setose and slightly clavate; proboscis dark brown, elongate, length about head height, and projecting ventrally; antenna (fig. 2A) black; scape about twice as long as pedicel; scape and pedicel setose; first flagellomere conical, tapering, and with short 2-articulated apical style.

Thorax: mostly black with dark metallic green reflections, pleura and humeral area covered by dense grey pruinosity; 1 postalar seta, 1 long and 1 short postsutural supra-alar setae; and 2 presutural intra-alar setae present; notopleuron with 4 strong setae among shorter hairs; postpronotum with strong posterior seta and field of 7–8 weaker anterior setae; prothoracic collar (pronotum) with row of short setae; proepisternum with field of lateral hairs and with anterior fan of 10–12 long setae; laterotergite and remainder of pleura bare of setae; scutellum with some supernumerary setae; metanotum broad and slightly bulging.

Legs: black, but coxae covered with dense grey pruinosity and concolorous with pleura; CI with long anterior setae and hairs, and CII and CIII with stronger lateral setae; all tarsi with strong black claws and large yellowish pulvilli; I: 3.5; 3.7; 1.5/ 0.5/ 0.3/ 0.2/ 0.4; FI with only short vestiture; TI with 3-4 pairs of short ad-pd setae, and anteroapical comb of 8-10 short, even setae; II: 3.6; 3.0; 1.5/ 0.7/ 0.4/ 0.2/ 0.5; FII with short vestiture and with stronger anterior, av, and posterior subapical setae; TII with 4–5 irregular ad-pd setal pairs, and some short ventral setae along length; III: 5.5; 4.7; 2.0/ 1.2/ 0.7/ 0.4/ 0.6; FIII with short hairs and with stronger subapical anterior, posterior, av and pv setae; TIII with 7–8 irregular ad-pd setal pairs, and some short ventral setae; $IIIt_1$ with 1–2 short dorsal setae.

Wing: membrane smoky; costa demelanised along posterior wing margin; brownish stigma present under distal R_1; costa haired, but other veins bare; A_1 present distally only as weak fold; A_2 present only as trace; anal angle well developed; lower calypter yellowish with yellow setae; halter yellow.

Abdomen: dark brown-black, and covered with grey pruinosity and black vestiture; terga with only moderately long setae along posterior margins; each tergum of preabdomen with four oblong depressions or abdominal plaques on lateral margin, with additional depressions on corresponding sterna; segment 7 with well-developed tergum and sternum, not differentiated from segments anteriad; tergum 8 only slightly reduced; sternum 8 unmodified; hypopygium (fig. 2B). Phallus along with oblong sperm pump internally extending into abdominal segments 7 and 8; epandrium setose, and distinct surstylus not evident.

Female: similar to male except as noted: frons wider, such that ocellar triangle not adjoining eyes; face and clypeus both wider; It_1 not swollen; oviscapt (fig. 2C).

Remarks

Cunomyia unica is known from late November to early February in western Tasmania. It has been collected in malaise traps, yellow pans, at light, and swept from vegetation in a variety of montane habitats, including streams in subalpine woodland, and alpine lakes, heath and herbfields. Its behaviour and swarming activity are unknown. The specific epithet *unica* refers to the genus currently comprising a unique species.

MORPHOLOGICAL NOTES

Two morphological characters of *Cunomyia* require further discussion.

(1) Cercus

In most members of the tribe Hilarini, the male cercus (= dorsal lamella in Chvála 1983) is rather small and desclerotised, and fused laterally with the surstylus (= bacilliform sclerite of Cumming & Sinclair) and epandrium (J. Cumming & B. Sinclair, pers. comm.). The cercus in the tribe Empidini, on the other hand, is often enlarged and functions as a clasping organ.

Cunomyia has an enlarged sclerotised male cercus, which is divided in to a distinctive digitiform "clasping cercus" and smaller "cercal plate" (fig. 2B). Sinclair (1995) discussed a similar division of the cercus in the subfamily Clinocerinae, and considered this character state to be a synapomorphy for a major clade within that subfamily. Further, he noted that, although the male cercus is modified for clasping in the ground plan of the clade (Empidinae + Hemerodrominae), it remains undivided. Also, the clasping cercus of *Cunomyia* is erect while that of most Empidinae lies horizontally (B. Sinclair, pers. comm.). Therefore, the distinctly divided cercus in *Cunomyia* is seen as an independent development or homoplasy with the subfamily Clinocerinae. [Here it must be noted that the median surface of the clasping cercus in Clinocerinae has modified hairs (Sinclair 1995), which are absent on *Cunomyia*.] Possibly *Cunomyia* is basal within the Hilarini, sharing a clasping cercus with its sister group, the Empidini, but became divided secondarily in the genus.

(2) Male postabdomen

Most Hilarini have abdominal segments 2–6 with well-developed terga and sterna, while terga 7 and 8 are either reduced in size and/ or partially desclerotised to allow the hypopygium to be flexed anteriorly. This is often marked by a distinct narrowing and flattening of the male postabdomen anteriad of the hypopygium.

By contrast, in *Cunomyia* abdominal segment 7 is well developed and subequal with the pre-abdominal segments, and segment 8 is only slightly reduced in size but retains a well-sclerotised tergum. As a result, the *Cunomyia* hypopygium is unflexed and confined to the end of the abdomen, held in place by the collar-like segments 7 and 8 (figs 1, 2A). I have not seen other Hilarini with this structure, and regard this as a primitive condition. These two related characters can be stated in the following formula:

Character: plesiomorphic (ancestral) state; apomorphic (derived) state.

(1) Abdominal terga 7 and 8: well-developed, sclerotised, collar like; reduced in size, desclerotised, and/ or flattened.

(2) Hypopygium: erect, unflexed and confined to end of abdomen; flexed anteriorly over terga 7 and 8.

SYSTEMATIC POSITION OF *CUNOMYIA*

Cunomyia is therefore presumed to be primitive with respect to other Hilarini in its clasping cercus and postabdominal structure. However, the entire tribe needs considerable redefinition at the generic level before its phylogenetic position can be ascertained.

ACKNOWLEDGEMENTS

I thank the following curators for loan of specimens: M. Moulds (AMS); P. Cranston (ANIC); D. Webb (INHS); K. Walker (MVM). Brad Sinclair provided valuable comments and insights on empidid morphology and systematics. Sue Bullock drew the male genitalic figure. Carmen Zurl drew the habitus of *Cunomyia unica*. This research was supported by Australian Research Council grant A19232651, for study of the systematics of Australian Empidinae.

REFERENCES

BICKEL, D.J., 1996: *Thinempis*, a new genus from Australia and New Zealand (Diptera: Empididae), with notes on the tribal classification of the Empidinae. *Syst. Entomol.* 21: 115–128.

CHVÁLA, M., 1983: The Empidoidea (Diptera) of Fennoscandia and Denmark II. General Part. The Families Hybotidae, Atelestidae, and Microphoridae. *Fauna Entomol. Scand.* 12: 1–279.

COLLIN, J.E., 1933: Empididae, Part 4. *DIPTERA OF PATAGONIA AND SOUTH CHILE.* British Museum (Natural History), London: 334 pp.

CUMMING, J.M., SINCLAIR, B.J. & WOOD, D.M., 1995: Homology and phylogenetic implications of male genitalia in Diptera - Eremoneura. *Entomol. Scand.* 26: 120–151.

ELTRINGHAM, H., 1928: On the production of silk by species in the genus *Hilara* Meig. *Proc. R. Soc. Lond.* (B) 102: 122–135.

MCALPINE, J.F., 1981: Morphology and terminology. *In* McAlpine, J.F. *et al.*: *MANUAL OF NEARCTIC DIPTERA, VOL. 1.* Agriculture Canada, Ottawa: 9–64.

PLANT, A.R. 1995. A new genus of Empidinae (Diptera: Empididae). *NZ Entomol.* 18: 25–28.

SINCLAIR, B.J., 1995: Generic revision of the Clinocerinae (Empididae), and description and phylogenetic relationships of the Trichopezinae, new status (Diptera: Empidoidea). *Can. Entomol.* 127: 665–752.

SMITH, K.G.V., 1969: The Empididae of southern Africa (Diptera). *Ann. Natal Mus.* 19: 1–342.

WHITE, A., 1917: The Diptera-Brachycera of Tasmania. Part II. Families Asilidae, Bombyliidae, Empidae, Dolichopodidae and Phoridae. *Pap. Roy. Soc. Tasm.* 1916: 148–266.

(accepted 28 September 1998)

AMATHAMIDE ALKALOIDS IN THE PYCNOGONID, *STYLOPALLENE LONGICAUDA*, EPIZOIC ON THE CHEMICALLY DEFENDED BRYOZOAN, *AMATHIA WILSONI*

by J. Sherwood, J. T. Walls and D. A. Ritz

(with four tables, two text-figures and one plate)

SHERWOOD, J., WALLS, J.T. & RITZ, D.A., 1998 (31:xii): Amathamide alkaloids in the pycnogonid, *Stylopallene longicauda*, epizoic on the chemically defended bryozoan, *Amathia wilsoni*. *Pap. Proc. R. Soc. Tasm.*, 132: 65–70. ISSN 0080–4703. Department of Entomology, University of Illinois at Urbana-Champaign, 505 S. Goodwin, Urbana, IL 61801, USA (JS); Department of Anatomy and Physiology, University of Tasmania, GPO Box 252-24, Hobart, Tasmania, Australia 7001 (JTW); and Zoology Department, University of Tasmania, GPO Box 252-5, Hobart, Tasmania, Australia 7001 (DAR).

Amathamides comprise a group of brominated alkaloids found in the bryozoan, *Amathia wilsoni* Kirkpatrick (Gymnolaemata: Ctenostomata). We tested a crude bryozoan extract and purified amathamide C for their ability to deter feeding by fish, *Acanthaluteres spilomelamurus* (Quoy and Gaimard, 1824) (leatherjacket), in laboratory assays. Food pellets made with crude extracts (1% dry weight) caused 94% inhibition of artificial pellet acceptance, while amathamide C at 0.1% dry weight caused 86% inhibition. These results suggest amathamides serve as chemical defences of *A. wilsoni*. Because bryozoans are often colonised by epibionts, we also examined representatives of the epizoic community on *A. wilsoni*, using gas chromatography/mass spectrometry (GCMS) for the presence of amathamides. Of 34 epizoic species tested, only one, the sea spider *Stylopallene longicauda* Stock which was present in high average densities, contained amathamides in concentrated amounts even when deprived of food for 36 hours. In view of the demonstrated feeding deterrence of amathamides in bryozoans, the relatively high epizoic density of *S. longicauda* and its apparent aposematic colouration suggest that amathamides may also function as chemical defences for *S. longicauda*.

Key Words: pycnogonid, *Styllopallene longicauda*, bryozoan, secondary metabolites, predator-prey interactions, alkaloids, chemical defence, *Amathia wilsoni*

INTRODUCTION

Bryozoans are sedentary, colonial, marine invertebrates. Approximately 4000 extant species and over 15 000 recorded fossil species have been described (Ryland 1970). Colony morphology is diverse, and often a single colony overgrows a large area, providing a relatively complex microhabitat in which other invertebrates may take refuge (Buss 1979). Secondary metabolites have been identified from marine bryozoans (Christophersen 1985, Anthoni *et al.* 1990) and characterised as either alkaloids or bryostatins, a group of 15 macrocyclic lactones possessing antineoplastic activity (Anthoni *et al.* 1990). Despite the structural diversity of bryozoan secondary metabolites, few studies have examined their ecological roles. Montanari *et al.* (1996) found the volutamides, also halogenated alkaloid metabolites, from *Amathia convoluta* Lamouroux, to deter feeding by co-occurring predators. Further, volutamides showed toxicity towards larvae of a sympatric hydroid. Halogenated alkaloids from the congener, *A. wilsoni*, have antibacterial properties (Walls *et al.* 1993) and might also function in chemical defence.

Bryozoan epifaunal assemblages have also been characterised (Rao & Ganapati 1980, Stebbing 1971, Gordon 1971), but little attention has been given to the potential presence of chemically mediated associations between bryozoan hosts and their epizoans. Carté & Faulkner (1986) demonstrated that three nudibranch species sequester secondary metabolites produced by the bryozoan *Sessibugula translucens*; additionally, one of the species, *Tambja eliora*, is chemically attracted to the bryozoan and its secondary metabolites, tambjamines, at concentrations less that 10^{-10} M. Aside from this study, few investigations have been made into the extent to which bryozoan secondary metabolites are found in marine food webs, and the number of studies documenting specialist invertebrate predators in marine ecosystems remains low relative to terrestrial specialist insects (Hay 1992). This situation seems likely to change, since Cronin *et al.* (1995) pointed to a growing number of reports of specialised feeding among small sedentary consumers that live on chemically defended hosts.

Amathia wilsoni Kirkpatrick (Gymnolaemata: Ctenostomata) is an arborescent, chitinous (ctenostome) bryozoan that contains amathamides (fig. 1) (Blackman & Matthews 1985, Blackman & Green 1987, Blackman & Fu 1989). These brominated alkaloids display antimicrobial activity (Walls *et al.* 1993) and are found in *A. wilsoni* in

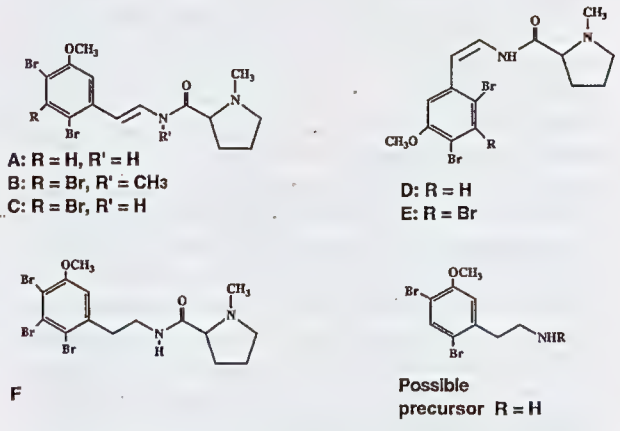


FIG. 1 Structure of amathamide alkaloids A-F and a possible precursor from the bryozoan Amathia wilsoni.

concentrations up to 9% dry weight in some regions of the colony (Walls *et al.* 1991). We tested the ability of amathamides to deter feeding by leatherjackets, *Acanthaluteres spilomelamurus*, grazing fish sympatric with *A. wilsoni*. Additionally, to investigate the possibility of chemically mediated feeding specialisation by invertebrate predators, we screened representatives of the epizoic community of *A. wilsoni* for the presence of amathamides.

MATERIALS AND METHODS

Feeding Deterrence of Amathamides

A. wilsoni is a common bryozoan in Tasmanian coastal waters (Bock 1982) and occurs abundantly in the coastal rocky reef habitat. Colonies are variable brown to green in colour, erect foliose in structure and range in diameter from 50 to 300 mm. To test the palatability of *A. wilsoni* chemical extracts, either a crude extract of the bryozoan or the purified alkaloid amathamide C, the major secondary metabolite found in *A. wilsoni* (Walls *et al.* 1991), was incorporated into food pellets and fed sequentially to test fish, juvenile leatherjackets, *Acanthaluteres spilomelamurus* (Monacanthidae: Tetraodontiformes). Leatherjackets are common generalist feeders in Tasmanian coastal waters and are widely sympatric with *A. wilsoni*. Further, bryozoans have been isolated from leatherjacket gut contents (N. Barrett, pers. comm.). Test fish were collected throughout 1991 from North West Bay, southern Tasmania, Australia (43°3'S, 147°16'E). A 50 mm mesh seine was used to trap fish above sea grass beds in the bay. Fish were kept in a large aerated holding tank (700 x 350 x 500 mm) until used in experiments and were fed standard food pellets formulated for Atlantic salmon (Gibsons Ltd, Hobart, Tasmania).

Test diets for *A. spilomelamurus* consisted of 10 ml water, 0.2 g agar, 0.2 g fish pellets and 1.0 ml dichloromethane (DCM). Agar, water and crushed fish pellets were boiled and cooled to 60°C before addition of DCM. Droplets of liquid mixture were pipetted (10 µl) onto petri dishes and then covered and cooled to solidification. Treatment pellets were made identically, except a bryozoan extract or amathamide C in DCM was added to the agar mixture and the solvent allowed to evaporate before administration.

Crude extracts were made from colonies of *A. wilsoni* collected from waters 5–20 m deep surrounding Arch Island, southeastern Tasmania (43°17'S, 147°10'E). Colonies were cleaned of any visible fouling organisms and kept at –20°C before freeze-drying for 48 hours. One hundred grams of wet material was freeze dried, milled and extracted with distilled DCM (Walls *et al.* 1991) and rotary-evaporated to dryness. Before incorporation into food pellets, a small amount of dried extract was redissolved in 0.9 ml DCM and analysed by gas chromatography/mass spectrometry. A Hewlett-Packard 5890A GC/MS was used for detection of amathamides, using selected ion monitoring (Walls *et al.* 1991). The amount of crude extract added to pellets produced an approximate amathamide concentration of about 1% of pellet dry weight. Previous work estimated total amathamide content in one colony at 1% dry weight and amathamide C content at 0.5% dry weight, i.e. approximately half of total (Walls *et al.* 1991).

The most abundant amathamide in *A. wilsoni*, amathamide C (Walls *et al.*, 1991), was purified by following the procedures of Blackman & Green (1987) and tested for feeding deterrence. To ensure pure amathamide C was obtained, GC/MS was performed on the extract before incorporation into treatment pellets. Pellets were made as above with crude extracts, except final concentrations of amathamide C were approximately 0.1% of food pellet dry weight. We did not have enough purified amathamide C to mimic the natural concentration in *A. wilsoni*. Separate feeding assays testing the effects of added DCM on pellet acceptability showed that the solvent did not change feeding behaviour (Walls 1993).

Two separate feeding trials were performed in a manner similar to those described by Gerhart *et al.* (1991). In each trial, 30 individual test fish were starved for 24 hours before being offered, sequentially, a control pellet, treatment pellet, treatment pellet, and finally another control pellet. Rates of pellet acceptance for the two treatments were compared statistically using G-tests for independence with Yates' correction (Sokal & Rohlf 1981). Percentage inhibition of feeding attributed to treatments relative to controls was calculated (from combined data) as the difference between control and treatment acceptance rates, divided by the control rate (Gerhart *et al.*, 1991). Also, first and last control pellet acceptance was compared statistically as above. Thus, the use of single pellets allowed for detection of facilitation or inhibition of feeding during the experiment. Thirty sets of four pellets were offered to each fish in each trial, and results were scored as either one for completely eaten, one-half for a mouthed and then rejected pellet, and zero for an untouched pellet. Scores for both control and treatment pellets were pooled and percentages of number eaten were calculated.

Alkaloid Screening and Epizoic Community Density

Ecologically significant interactions of an epibiont with its host might be a function of abundance, so densities of pycnogonids on collected bryozoans were estimated. Twelve colonies of *A. wilsoni* were collected during July and August 1992, from waters 9–15 m deep at Deep Glen Bay, Forestier Peninsula, southeastern Tasmania, Australia (42°58'S and 147°58'E). Ten colonies were preserved in 7% formalin and transferred to 70% ethanol for collection of epizoans. For comparison, two colonies of each of three species of catenicellid cheilostome bryozoan were collected and preserved to determine densities of co-occurring pycnogonid species. These calcified bryozoans, *Orthoscuticella ventricosa* Busk, *Costaticella hastata* Busk and *Paracribricellaria cribraria* Busk, are also arborescent, contain brominated alkaloids and are sympatric with *A. wilsoni*. Plastic bags were placed over individual colonies, which were then pulled from the substrate at the holdfast. Pycnogonid densities were expressed in terms of bryozoan colony volumes which were measured by water displacement. Pycnogonids were removed by shaking individual bryozoan colonies in a bucket of water, which was then filtered, using a 500 µm mesh. Pycnogonids were then counted and identified. Total abundance was divided by colony volume and multiplied by 100 to calculate a size-specific pycnogonid density for each bryozoan colony as number of individuals per 100 ml bryozoan colony.

From two remaining colonies, pycnogonids were collected, identified and maintained in aerated sea water aquaria for 36 hours to allow passage of gut contents. After that time, individuals were freeze-dried for 48 hours and

then extracted once for 24 hours with 3 ml DCM. Additionally, to compare pycnogonid extracts with bryozoan host extracts, frond tip sections of *A. wilsoni* were freeze-dried and extracted. Resultant crude extracts were then screened for the presence of amathamides by GC/MS. Retention times and mass spectrometric fragmentation signatures of extracts were analysed and compared between bryozoan host and epizoan for amathamide presence.

RESULTS

Predator Deterrence of Bryozoan Alkaloids

Both the crude bryozoan extract and amathamide C significantly lowered pellet acceptance rates relative to control rates (table 1) (amathamide C: treatment pellet 1, Yates' corr. G=30.9, df=1, P<0.005; treatment pellet 2, Yates' corr. G=40.0, df=1, P<0.005; crude extract: treatment pellet 1, Yates' corr. G=47.4, df=1, P<0.005; treatment pellet 2, Yates' corr. G=56.6, df=1, P<0.005). Control pellet acceptance rates did not differ significantly between the beginning and the end of either amathamide C or crude extract experiments (Yates' corr. G=0.0, df=1, P>0.10). Results of both experiments were combined to calculate the relative potency of 0.1% amathamide C and 1.0% crude extract treatments. Feeding inhibition was slightly higher for the crude extract (94% inhibition of pellet consumption relative to controls), than for 0.1% amathamide C alone (87.5% inhibition) (table 1). Since these experiments were conducted at different times, the significance of this difference could not be tested. Rates of acceptance of first and last control pellets were not significantly different (table 2), nor were those of first and second test pellets, though fewer of the second were taken than the first. Thus, no significant facilitation or inhibition of feeding by the leatherjackets was detected during the experiments; this suggests a lack of a learned-aversion response in this species.

Alkaloid Screenings and Epizoic Community Density

Thirty-four epizoic species were screened for amathamides (table 3). Of these, bryozoan predators might have been expected only among the gastropods, polychaetes, pycnogonids and possibly decapods. In fact, only one species, the pycnogonid *Stylopallene longicauda*, contained amathamides. Gas chromatograms of pycnogonid extracts showed peaks with retention times characteristic of amathamides (fig. 2) (Walls *et al.* 1991, Blackman & Matthews 1985, Blackman & Green 1987). Mass spectrometric fragmentation patterns verified, by the presence of a predominant 84 amu signal corresponding to the N-methylpyrrolidine ion, four amathamide peaks in the gas chromatogram of *S. longicauda*.

From the ten bryozoan colonies, the average density of *S. longicauda* is an order of magnitude greater than its density on the catenicellid bryozoans and any other pycnogonid found on *A. wilsoni* (table 4). High variance in density estimated was due to the presence of three colonies possessing upwards of 160 pycnogonid juveniles.Several attempts to observe feeding by *S. longicauda in situ* on a bryozoan colony were unsuccessful.

TABLE 1
Relative palatability of pellets containing crude extract of *Amathia wilsoni* and amathamide C to leatherjackets (*Acanthaluteres spilomelanurus*)

Treatment	No. pellets	Pellets eaten (%)*	Feeding inhibition (%)
Crude Extract	60	5.8	94
Control	60	94	6
Amathamide C	60	12.5	87.5
Control	60	90	10

* Percentage of first and second pellets eaten for both treatments was significantly different to percentage of control pellets eaten (G-test, $p < 0.005$). See text for other statistical details.

TABLE 2
Rates of acceptance of first and last control pellets by *Acanthaluteres spilomelanurus*

Treatment	Eaten* (N)	Not eaten (N)	Yates' corrected G
Crude Extract			
First Control Pellet	28	2	0.0
Last Control Pellet	28.5	1.5	
Amathamide C			
First Control Pellet	26.5	3.5	0.0
Last Control Pellet	27.5	2.5	

* Pellets that were mouthed and rejected were scored as 0.5.

TABLE 3
Epizoic organisms screened for amathamides

Taxon*	No.†	Species‡
Amphipoda	7	nd
Ascidiaceae	2	nd
Bivalvia	2	nd
Bryozoa	2	*Emma rotunda, Membranipora perfragilis*
Decapoda	2	nd
Echinoidea	1	nd
Gastropoda	5	nd
Hydrozoa	1	nd
Isopoda	1	nd
Ophiuroidea	1	nd
Polychaeta	4	*Trypanosyllis zebra*, Syllidae sp., 2 nd
Porifera	1	nd
Pycnogonida	5	*Achelia assimilis, Stylopallene longicauda, Pseudopallene ambigua, P. pachychiera,* P. sp.

* Epizoic taxa.
† Number of species per taxon.
‡ Species names (when determined) of organisms extracted and analysed for presence of amathamides using GC/MS; nd = not determined.

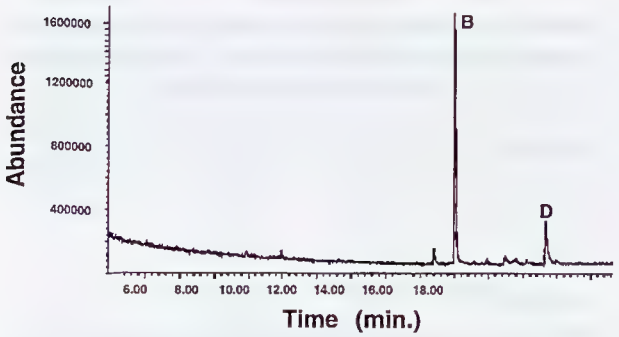


FIG. 2 — Selected Ion Monitoring gas chromatogram (SIM) trace of DCM extract of Stylopallene longicauda. *Peaks represent amathamides verified by mass spectrometry. See Walls* et al. *(1991) for procedural details. B – amathamide B; D – amathamide D.*

TABLE 4
Average densities of ten species of pycnogonid epizoic on *Amathia wilsoni* and three catenicellid bryozoans

Pycnogonid	*Amathia wilsoni*† n=10	Catenicellids† n=6
*Achelia assimilis**	0.9 ±2.2	0.2 ±0.5
Achelia transfugoides	0.2 ±0.6	0.4 ±0.7
Ammothea ovatoides	0.5 ±1.2	0
Ammotheidae sp.	0.1 ±0.4	0
*Pseudopallene pachychiera**	0.1 ±0.3	0.2 ±0.4
*P. ambigua**	0.7 ±2.3	0.8 ±1.2
P. sp.1	0.2 ±0.4	0.2 ±0.5
P. sp.2	0.2 ±0.5	0
Pycnogonum aurilineatum	0.1 ±0.4	0
*Stylopallene longicauda**	53.8 ±43.9	0.4 ±1.1

* Species extracted and screened for amathamide alkaloids.
† Densities reported as number of individuals per 100 ml bryozoan colony.

DISCUSSION

Amathamides produced by *A. wilsoni* deter feeding by *A. spilomelamurus* and may serve as chemical defences against generalist predators. Levels of inhibition associated with amathamide C-treated pellets were slightly lower than levels of inhibition associated with crude extract-treated pellets. This could be because absolute amounts of secondary metabolites in the pellets were different. But if it was an indication either that other amathamides deter feeding more effectively than amathamide C, or that mixtures of the amathamide array might be working more effectively than amathamide C alone, it would repay further study. For example, synergistic interactions have been documented for chemically defended terrestrial plants (Berenbaum & Neal 1985, Berenbaum 1985) and for marine invertebrates (Hay *et al.* 1994). Variation in physiological effects among compounds with similar structures is documented (Hay & Fenical 1988). *A. wilsoni* possesses a range of structurally similar alkaloids (fig. 1) that may be more effective against a greater range of potential predators than individual compounds.

Hay *et al.* (1987) found seaweed secondary metabolites to be deterrent to predatory fish and sea urchins, but found no effect on feeding by an amphipod. It would be interesting to test the effectiveness of amathamides against generalist invertebrate predators of bryozoans. As food preferences often change with maturity, assumptions about the similarities in diet between adult and juvenile fish must also be made with care. Our feeding trials with *A. spilomelamurus,* however, suggest that amathamides play a part in chemically defending *A. wilsoni* from predation.

Distribution patterns of amathamides support present feeding assay results which suggest amathamides act as chemical defences for the bryozoan (Walls *et al.* 1991). In this study, Walls *et al.* showed amathamides to vary in concentration and distribution within single colonies; outermost, exposed tips had an alkaloid content of nearly 9% dry weight, while basal parts were devoid of alkaloids. Samples taken midway between tips and base yielded intermediate concentrations of about 1% dry weight. Assuming some metabolic cost of amathamide chemical defence production, and that the exposed and actively asexually reproducing bryozoan tips are more valuable to the colony than other regions, amathamide allocation in *A. wilsoni* is consistent with current optimal defence theory. This theory predicts that plant parts most important and susceptible to predation will be most defended (Rhodes 1979). Such regions of a plant, therefore, should contain higher concentrations of chemical defences than other relatively unexposed and unimportant regions (Zangerl & Bazzaz 1992).

Many associations between pycnogonids and marine invertebrates have been documented (scyphozoans – Child & Harbison 1986, Arnaud & Bamber 1987; hydroids – Russell & Hedgepeth 1990, Staples 1987; bivalves – Ohshima 1933, Ogawa & Matsuzaku 1985, Benson & Chivers 1960; opisthobranchs – Piel 1991, Arnaud 1978; starfish – Stock 1981; ophiuroids – Sloan 1979; bryozoans – Wyer & King 1973), and pycnogonids are among the few documented specialised predators of bryozoans (Ryland 1976). The present study provides another example of a sea spider–host interaction. *S. longicauda* has only ever been reported from Westernport Bay, Victoria, where it is very common on *Amathia biseriata.* Other sea spiders counted, some even in the same family as *S. longicauda,* do not occur in such high densities on *A. wilsoni* or any of the three catenicellids. The relatively low density of *S. longicauda* on the sympatric catenicellid bryozoans, one of which also produces halogenated alkaloids (Blackman *et al.* 1987), indicates *S. longicauda* preferentially resides amongst the fronds of *A. wilsoni.*

The presence of amathamides in starved specimens of *S. longicauda* may indicate these amathamides are sequestered in tissues of the sea spider for defensive purposes. That the density of *S. longicauda* on *A. wilsoni* was an order of magnitude greater than that of any other pycnogonid identified in this study (table 4), further supports the notion that *S. longicauda* may be a specialist predator on *A. wilsoni*; indeed the density of *S. longicauda* on *A. wilsoni* is the highest reported to date (Anonymous 1980, Arnaud & Bamber 1987). Finally, *S. longicauda* appears to be aposematically coloured; individuals are circularly banded with strongly contrasting black and white regions, a pattern that could clearly present itself over all wavelengths of visible light, and hence depths (pl. 1). This would be consistent with Lindquist & Hay (1996), who described a

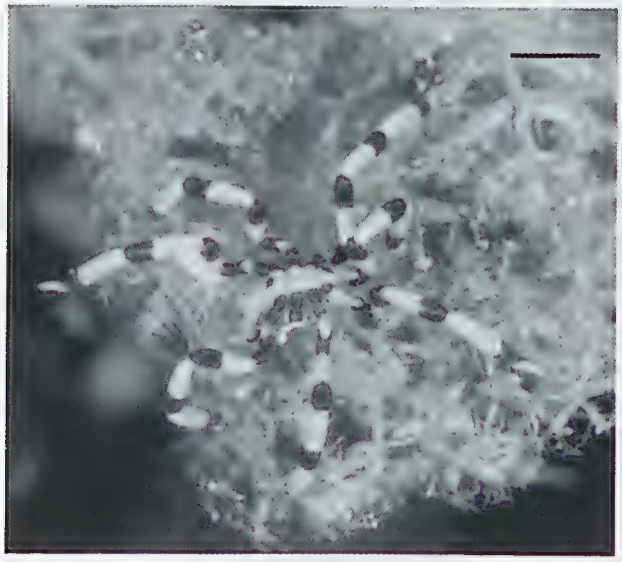


PLATE 1
Stylopallene longicauda *on* Amathia wilsoni. *Note black and white banding as possible aposematic coloration. Bar is 0.5 cm.*

positive correlation between frequency of bright colouration of larvae and their unpalatability to fish. Reports of pycnogonids as prey are inconsistent. Although they may be a relatively poor food item (King 1973, Arnaud & Bamber 1987, Anonymous 1980), they have recently been found in gut contents of blenniid fishes (Krapp & Nieder 1993). Thus, there is some evidence of predation on sea spiders, which could provide a selective force for defence, gained through a particular feeding specialisation.

There are few reported cases of chemical defences in pycnogonids. Tomaschko (1994) demonstrated that the sea spider *Pycnogonum littorale* possesses moulting hormones, ecdysteroids, which deter feeding by the common shore crab, *Carcinus maenas*. Along with this recent finding, our study documents possible chemical defences in these primitive marine chelicerates. Moreover, our findings suggest *S. longicauda* may be preferentially associating with *A. wilsoni* in order to gain these chemical defences. It remains to be seen if the many documented associations between sea spiders and other marine invertebrates are chemically mediated.

ACKNOWLEGEMENTS

We would like to thank the Carl and Sarah Morgan Foundation and the William R. Murchie Fund for partially funding the research. We also thank Noël Davies for his GC/MS expertise. R. Mawbey and R. Holmes of the University of Tasmania assisted in fieldwork. Pycnogonids were expeditiously identified by D. Staples of the Museum of Natural History, Victoria, Australia.

REFERENCES

Anonymous, 1980: Pycnogonids in N.E. Atlantic food webs: the uneaten sea spider? *Natl. Environ. Res. Counc. News J.* 2: 9–10.

Anthoni, U., Nielson, P.H., Pereira, M. & Christopherson, C., 1990: Bryozoan secondary metabolites: a chemo-taxonomical challenge. *Comp. Biochem. Phys.* 96B: 431–437.

Arnaud, F., 1978: A new species of *Ascorhynchus* (Pycnogonida) found parasitic in an opisthobranchiate mollusc. *Zool. J. Linn. Soc. Lond.* 63: 99–104.

Arnaud, F. & Bamber, R.N., 1987: Biology of Pycnogonida. *Adv. Mar. Biol.* 24: 1–96.

Benson, P.H. & Chivers, D.C., 1960: A pycnogonid infestation of *Mytilus californicus*. *Veliger* 3:16–18.

Berenbaum, M.R., 1985: Brementown revisited: Interactions among allelochemicals in plants. *In* Cooper-Driver G.A., Swain, T. & Conn, E.E. (Eds): *CHEMICALLY MEDIATED INTERACTIONS BETWEEN PLANTS AND OTHER ORGANISMS. Recent Adv. Phytochem.* 19. Plenum Press, New York: 139–169.

Berenbaum, M.R. & Neal, J.J., 1985: Synergism between myristicin and xanthotoxin, a naturally cooccurring plant toxicant. *J. Chem. Ecol.*11:1349–1358.

Blackman, A.J. & Fu, S.L., 1989: A B-phenylethylamine-derived possible biosynthetic precursor to the amathamide alkaloids from the bryozoan *Amathia wilsoni*. *J. Nat. Prod.* 52: 436–438.

Blackman, A.J. & Green, R.D., 1987: Further amathamide alkaloids from the bryozoan *Amathia wilsoni*. *Aust. J. Chem.* 40: 1655–1662.

Blackman, A.J. & Matthews, D.J., 1985: Amathamide alkaloids from the marine bryozoan *Amathia wilsoni* Kirkpatrick. *Heterocycles* 23: 2829–2833.

Blackman, A.J., Matthews, D.J. and Green, R.D., 1987: ß-carboline alkaloids from the marine bryozoan *Costaticella hastata*. *J. Nat. Prod.* 50: 494-496.

Bock, P.E., 1982: Bryozoans (Phylum Bryozoa). *In* Shepard, S.A. & Thomas, I.M. (Eds): *MARINE INVERTEBRATES OF SOUTHERN AUSTRALIA. PART I.* South Australian Government: 319–394.

Buss, L.W., 1979: Habitat selection, directional growth and spatial refuges: Why colonial animals have more hiding places. *In* Rosen, B. & Larwood, G. (Eds): *BIOLOGY AND SYSTEMATICS OF COLONIAL ORGANISMS.* Academic Press, London: 459–498

Carté, B. & Faulkner, D.J., 1986: Role of secondary metabolites in feeding associations between a predatory nudibranch, two grazing nudibranchs and a bryozoan. *J. Chem. Ecol.* 12: 795–804.

Child, C.A. & Harbison, G.R.A., 1986: A parasitic association between a pycnogonid and a scyphomedusa in midwater. *J. Mar. Biol. Assoc. UK* 66: 113–117.

Christophersen, C., 1985: Secondary metabolites from marine bryozoans: A review. *Acta Chem. Scand.* B 39: 517–529.

Cronin, G., Hay, M.E., Fenical, W. & Lindquist, N., 1995: Distribution, density and sequestration of host chemical defenses by the specialist nudibranch *Tritonia hamnerorum* found at high densities on the seafan *Gorgonia ventalina*. *Mar. Ecol. Prog. Ser.* 119: 177–189.

Faulkner, D.J. & Ghislen, M.T., 1983: Chemical defense and the evolutionary ecology of dorid nudibranchs and some other opisthobranch gastropods. *Mar. Ecol. Prog. Ser.* 13: 295–301.

Gerhart, D.J., Bondura, M.E. & Commito, J.A ., 1991: Inhibition of sunfish feeding by defensive steroids from aquatic beetles: structure-activity relationships. *J. Chem. Ecol.* 14: 1905–1917.

GORDON, D.P., 1971: Biological relationships of an intertidal bryozoan population. *J. Nat. Hist.* 6: 503–514

HAY, M.E., 1992: The influence of algal secondary metabolites in the evolution of marine specialist grazers. *In* Paul, V. (Ed.): *ECOLOGICAL ROLES OF MARINE NATURAL PRODUCTS.* Comstock, London.

HAY, M.E. & FENICAL, W., 1988: Marine plant herbivore interactions: the ecology of chemical defense. *Ann. Rev. Ecol. Syst.* 19: 111–145.

HAY, M.E., DUFFY J.E., PFISTER, C.A. & FENICAL, W., 1987: Chemical defense against different marine herbivores: are amphipods insect equivalents? *Ecology* 68:1567–1580.

HAY, M.E., KAPPEL, Q.E. & FENICAL, W., 1994: Synergisms in plant defenses against herbivores — interactions of chemistry, calcification, and plant quality. *Ecology* 75: 1714–1726.

KING, P.E., 1973: PYCNOGONIDS. Hutchinson, London.

KRAPP, F. & NIEDER, J., 1993: Pycnogonids as prey of blenniid fishes. *Cah. Biol. Mar.* 34: 38.

LINDQUIST, N. & HAY, M.E., 1996: Palatability and chemical defense of marine invertebrate larvae. *Ecol. Monogr.* 66: 431–450.

MONTANARI, A.M., FENICAL, W., LINDQUIST, N., LEE, A.Y. & CLARDY, J., 1996: Volutamides A-E, halogenated alkaloids with antifeedant properties from the Atlantic bryozoan *Amathia convoluta. Tetrahedron* 52: 5371–5380.

OGAWA, K. & MATSUZAKU, K., 1985: Discovery of bivalve-infesting Pycnogonida, *Nymphonella tapetis,* in a new host, *Hiatella orientalis. Zool. Sci.* 2: 583–589.

OHSHIMA, H., 1933: The adult of the bivalve-infesting pycnogonid, *Nymphonella tapetis* Ohshima. *Annot. Zool. Jpn* 14: 53–60.

PIEL, W.H., 1991: Pycnogonid predation on nudibranchs and ceratal autotomy. *Veliger* 34: 366–367.

RAO, K.S. & GANAPATI, P.N., 1980: Epizoic fauna of *Thalamoporella gothica* var. *indica* and *Pherusella tubulosa* (Bryozoa). *Bull. Mar. Sci.* 30: 34–44.

RHODES, D.F., 1979: Evolution of plant chemical defences against herbivory. *In* Rosenthal, G.A. & Janzen, D.H. (Eds): *HERBIVORES: THEIR INTERACTION WITH SECONDARY PLANT METABOLITES.* Academic Press, New York: 3–54

RUSSEL, D.J. & HEDGEPETH, J.W., 1990: Host utilization during ontogeny by two pycnogonid species, *Tanystylum duospinum* and *Ammothea hilgendorfi* parasitic on the hydroid *Eucopella everta* (Coelenterata: Campanulariidae). *Bijdr. Dierkd.* 60: 3–4.

RYLAND, J.S., 1970: *BRYOZOANS.* Hutchinson, London.

RYLAND, J.S. 1976: Pycnogonid predators. *Adv. Mar. Biol.* 14: 417–421.

SLOAN, A . 1979: A pycnogonid-ophiuroid association. *Mar. Biol.* 52: 171–176.

SOKAL, R.R. & ROHLF, F.J., 1981: *BIOMETRY, THE PRINCIPLES AND PRACTICE OF STATISTICS IN BIOLOGICAL RESEARCH.* 2nd edn. Freeman, San Francisco.

STAPLES, D.A., 1987: Association between pycnogonids and hydroids. *In* Bouillon, J. *et al.* (Eds): *MODERN TRENDS IN THE SYSTEMATICS, ECOLOGY, AND EVOLUTION OF HYDROIDS AND HYDROMEDUSAE.* Clarendon Press, Oxford.

STEBBING, A.R.D., 1971: The epizoic fauna of *Flustra foliacea* (Bryozoa). *J. Mar. Biol. Assoc. UK* 51: 283–300.

STOCK, J.H., 1981: Pycnogonides. 1. *Pycnosomia asterophila,* a sea spider associated with the starfish *Calliaster* from the Phillipines. Resultats des Campagnes Musorstom I. Phillipines (18–28 Mars, 1976). *Mem. Mus. Paris* 91: 309–312.

TOMASCHKO, K.H., 1994: Ecdysteroids from *Pycnogonum littorale* (Arthropoda, Pantopoda) act as chemical defence against *Carcinus maenas* (Crustacea, Decapoda). *J. Chem. Ecol.* 20: 1445–1455.

WALLS, J.T. 1993: Chemical ecology of four bryozoan species from Tasmanian coastal waters. Unpubl. PhD thesis, Univ. Tasm.

WALLS, J.T., BLACKMAN, A.J. & RITZ, D.A., 1991: Distribution of amathamide alkaloids within single colonies of the bryozoan *Amathia wilsoni. J. Chem. Ecol.* 17: 1871–1881.

WALLS, J.T., RITZ, D.A. & BLACKMAN, A.J., 1993: Fouling, surface bacteria and antibacterial agents of four bryozoan species found in Tasmania, Australia. *J. Exp. Mar. Biol. Ecol.* 169: 1–13.

WYER, D.W. & KING, P.E., 1973: Relationships between some British littoral and sublittoral bryozoans and pycnogonids. *In* Larwood, G.P. (Ed.): *LIVING AND FOSSIL BRYOZOA: RECENT ADVANCES IN RESEARCH.* Academic Press, New York: 199–208

ZANGERL, A.R. & BAZZAZ, F.A., 1992: Theory and pattern in plant defence allocation. *In* Fritz, R.S. & Simms, E.L. (Eds): *PLANT RESISTANCE TO HERBIVORES AND PATHOGENS: ECOLOGY, EVOLUTION AND GENETICS.* University of Chicago Press, Chicago.

(accepted 28 September 1998)

Replacement page

THE PRESUMED EXTINCT *ARGENTIPALLIUM SPICERI* (ASTERACEAE) REDISCOVERED IN TASMANIA

by Alex M. Buchanan

(with one text-figure and one plate)

BUCHANAN, A.M., 1998 (31:xii): The presumed extinct *Argentipallium spiceri* (Asteraceae) rediscovered in Tasmania. *Pap. Proc. R. Soc. Tasm.* 132: 71–73. ISSN 0080-4703. Tasmanian Herbarium, GPO Box 252-4, Hobart, Tasmania, Australia 7001.

The presumed extinct shrub *Argentipallium spiceri* (Asteraceae) has been rediscovered at the edge of *Eucalyptus obliqua* forest in southeastern Tasmania. Notes on its history, distribution and ecology are presented.
Key Words: *Argentipallium spiceri*, threatened species, Tasmania.

INTRODUCTION

Argentipallium spiceri was first collected by Augustus Simson from "the roadside, going from Longley towards the Sandfly coal seam" (Simson 1880). He found only one individual and gathered material from it over two successive summers, in December 1876 and January 1878. It was recognised as an undescribed species of *Helichrysum*, and a brief mention of its existence was made as an addendum in the Reverend William Spicer's *Handbook of the Plants of Tasmania*, published soon after the discovery (Spicer 1878). A portion of the material was sent to Ferdinand von Mueller in Melbourne who described it as *Helichrysum spiceri* (Mueller 1878). Subsequently, Rodway (1903) considered it to be conspecific with *H. obtusifolium* but Curtis (1963) reinstated it as a separate species. More recently, as part of a revision of the genus *Helichrysum* in Australia, Wilson (1992) transferred the taxon to the newly erected genus *Argentipallium*.

Until the present, only two further gatherings of this plant were known. Three sheets from the Rodway herbarium variously bear the location and date "Huonville" and "January 1892" and a gathering by W.M. Curtis from the Huon Highway near Scotts Road, south of Geeveston, is dated "4 Dec 1958". The known distribution is shown in figure 1. The species was presumed to be extinct (Briggs & Leigh 1995) and listed as such in the *Threatened Species Protection Act* (Tasmania), *Schedule 3, Part 2* (1995).

In November 1997, a specimen of a shrub, growing as a wildling, not cultivated, in a bush garden that merges into the forest, about 12 km southwest of Hobart was forwarded to the Tasmanian Herbarium for identification. The specimen was identified as *Argentipallium spiceri*, and this determination was confirmed following comparison with the holotype held at MEL.

METHODS AND MATERIALS

Material from the rediscovered plant was compared with the holotype held at MEL. All known herbarium specimens in Australia were located and examined (except BRI). Abbreviations of herbaria cited follow Holmgren *et al.* (1990). Field notes were made at known collection sites and species nomenclature follows Buchanan (1995).

DESCRIPTION

Argentipallium spiceri (F. Muell.) Paul G. Wilson, 1992
Nuytsia 8(3), 1992: 458

1878 *Helichrysum spiceri* F. Muell., *Fragm.* 11: 47.
1878 *Helichrysum* sp. Spicer, *A Handbook of the Plants of Tasmania*: 149.
1963 Curtis, *The Student's Flora of Tasmania* 2: 329.

Type: [Tasmania] near Longley, 12 January 1878, *Simson* 824.
Holotype: MEL!
Isotypes: HO!, Queen Victoria Museum, Launceston!

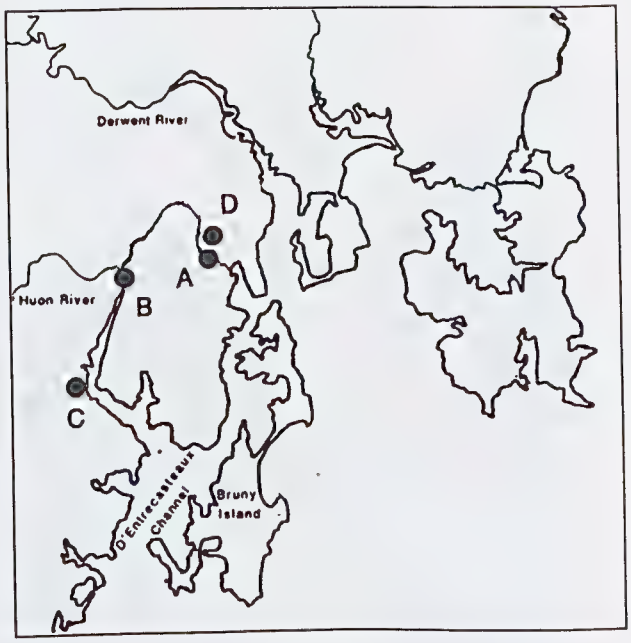


FIG. 1 — Location of the four known occurrences of Argentipallium spiceri. *A – Longley; B – Huonville; C – Scotts Road, Cairns Bay; D – Leslie Vale.*

Small, sparingly branched shrub to about 0.9 m tall. Branches slender and often lax, in some cases drooping when in flower, with a covering of long, appressed, fine, silky white hairs. Leaves linear, entire and mostly 10–15 mm long and 2–3 mm wide; base attenuate; apex with a small brown mucro; upper surface green, smooth to finely hispid; lower surface with a dense covering of felted, fine white to grey or very pale brown tomentum. Inflorescence a terminal panicle with up to six main branches; capitula 1–25, 10–15 mm diam; involucral bracts conspicuous, 5–6 mm long, brown and pink at the base (turning brown with age), white towards the apex, colourless below the middle; shorter, outer involucral bracts totally pink and sometimes with darker pink striations near the apex. Florets 3 mm long, with pappus to 4 mm long; achenes cylindrical, 0.8–1 mm long, 0.3 mm wide, with scattered, short, appressed hairs. (Pl. 1.)

OBSERVATIONS ON THE TYPE MATERIAL AND RELATED SHEETS

Three sheets of type material are known to exist in Australia. The holotype in MEL bears a label in Simson's handwriting: "824. Helichrysum ? nr Longley, 12 Jan 1878. I got this two successive summers; I saw but one plant, shrubby & bushy & got a lot of specimens each time", and has been annotated by Mueller. This makes it clear that the type material is from the second gathering.

There is an isotype in HO marked "Longley 1878" and inscribed "L. Rodway exchange with A[ugustus] S[imson]" in the handwriting of Janet Somerville who was caretaker of the Tasmanian Herbarium in the 1950s (Parham 1976). Having been part of Rodway's herbarium, the sheet was filed under *Helichrysum obtusifolium.*

A further isotype is held at the Queen Victoria Museum, Launceston, Tasmania. It is a small flowering specimen labelled "Longley, January 1878".

Another sheet in MEL, from Spicer's herbarium, is undated and unclearly numbered 26 or 36; it may be an isotype but has insufficient details to be certain.

A sheet in BRI bears the inscription in Simson's handwriting "36. Helichrysum Spiceri Mueller nr. Longley, new species found by myself - no one else ever found it. Is a shrubby plant". "A. Simson, Launceston" has been written in another hand. There is no date, and whether it is a type is, therefore, uncertain. The specimen is a single, small, flowering branchlet.

The whereabouts of Simson's other specimens is unknown. Many of Simson's duplicates of other material were included in the Spicer Herbarium when it was purchased by Michel Gandoger about 1890 and are now in LYON, in France (McGillivray 1973). However, despite a thorough search in the collection at LYON, no *Argentipallium spiceri* was found (Gaëtan Guignard, pers. comm.).

NOTES

Argentipallium spiceri is recognised by its multiple-headed inflorescence (pl. 1A) with conspicuous involucral bracts and by its open, branching habit and small leaves (pl. 1B). As a shrubby member of the genus *Argentipallium,* it most closely resembles *A. obtusifolium,* a species that, in Tasmania, is confined to the islands of the Furneaux group in Bass Strait. A third Tasmanian species of *Argentipallium, A. dealbatum,* is a widespread, perennial, herbaceous plant common in open, dry habitats. *A. spiceri* differs from both of these species in having a compound inflorescence with up to about 25 heads. Non-flowering plants might be mistaken for small specimens of *Cassinia aculeata* or *Ozothamnus ferrugineus,* both of which grow in the same area as the recently rediscovered plant.

There is considerable variation in morphological characters between the four collections. The 1892 collection differs from the type in having paler green leaves with a white (rather than brownish) indumentum on the underside and with a longer, paler mucro. The 1958 collection is even more different. It is a smaller, more compact plant and much more densely leafy. The leaves are grey, sparsely tomentose or sometimes hispid on the upper surface and are densely tomentose on the lower side. The panicles are

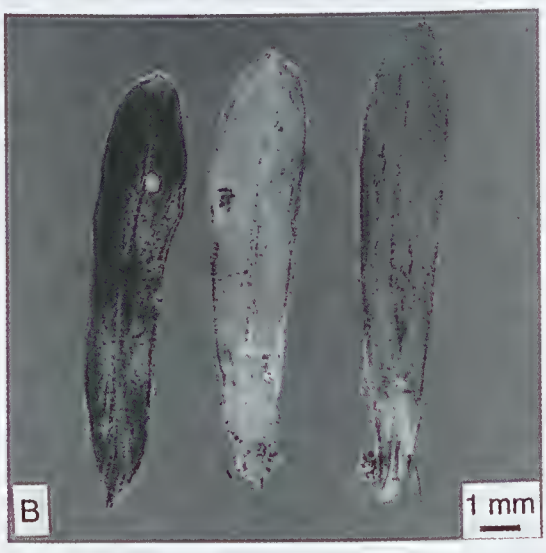


PLATE 1
Inflorescence (A) and leaves (B) of Argentipallium spiceri.

more compact and terminate clustered axillary shoots as well as the main axes.

The recently discovered plant reported in this paper is a sparingly branched, open shrub, with slender branches drooping when in flower, promoting the growth of small, lateral shoots. The leaves are grey-green and scabrid on the upper surface and white tomentose below.

LOCATION AND ECOLOGY

The site of Augustus Simson's original, single plant, found in 1876, is difficult to locate. Although the village of Sandfly is only 1 km south of Longley, the Sandfly coal seam that he refers to is at Kaoota (Bacon 1991), a further 5 km to the south. Mining was already in progress there by 1877 (Anon. 1877). The geology varies from sandstone between Longley and Sandfly to mostly dolerite south of Sandfly. Nevertheless, almost all of the forest in this area is dominated by *Eucalyptus obliqua*.

The 1892 collection by L. Rodway cannot be precisely located. The stated locality, Huonville, a small town, is probably given as simply the nearest named place. Rodway also notes that it is a "much branched straggling undershrub ...", inferring a forest or woodland habitat.

The 1958 collection by W.M. Curtis, although not precisely located on the label, was almost certainly collected about 100 to 200 m southeast of the intersection of Scotts Road with the Huon Highway, between Geeveston and Waterloo (M. Allan, pers. comm., and on-site discussion with W.M. Curtis, March 1998). This area is dominated by *E. obliqua* open forest with scattered trees of *E. ovata* on dolerite. The habitat was described as "dry bank - roadside".

The newly discovered location at Leslie Vale is on the edge of *E. obliqua* forest, where it grades into drier *E. pulchella* and *E. viminalis* open forest or woodland at the crest of a gentle, south-facing slope. The understorey is open, with scattered *Banksia marginata, Bedfordia salicina, Exocarpos cupressiformis, Leptospermum scoparium* and *Pultenaea juniperina* and with clumps of *Lomandra longifolia* and *Diplarrena moraea*. The underlying rock is dolerite with a shallow, rocky, clay soil. The soil on which the plant is growing was disturbed about ten years ago.

OTHER SPECIMENS EXAMINED

Longley, Huon Road, s.d., *A. Simson 36* [or *26*](ex herb. Spicer)(MEL 2042930); nr. Longley, s.d., *A. Simson 36* (BRI)[facsimile only seen]; Huonville, Jan 1892, *L. Rodway 392a* (HO 12691); Huonville, s.d., *L. Rodway 392a* (HO 12690); Huonville, s.d., *L. Rodway s.n.* (HO 12692); near Scotts Rd turnoff, Cairns Bay, Huon Highway, 4 Dec 1958, *W.M. Curtis s.n.* (HO 52623); Leslie Vale, Nov 1997, *P.J. Eberhard s.n.* (HO 323423); Leslie Vale, 13 Feb 1998, *A.M. Buchanan 15085* (HO 324666).

ACKNOWLEDGEMENTS

Particular thanks are due to Jo Eberhard as the discoverer of the rare plant and for allowing unhindered access to her property during the months that followed. The directors of LYON, NT, BRI, NSW, CANB, AD, PERTH, MEL and Queen Victoria Museum kindly checked their holdings for material. The latter two made specimens available. Monika Wells kindly searched the database of the Mueller Correspondence Project. I also thank Gintaras Kantvilas for his comments on earlier drafts of the manuscript. Andrew Rozefelds provided the photographic expertise.

POSTSCRIPT

A search of the area surrounding the rediscovered plant has not been successful in locating further individuals (A.M. Gray, pers. comm.). Propagation by cuttings has been successful but seed germination has not, there apparently being no viable seed (N. Papworth, pers. comm.).

REFERENCES

Anon., 1877: *House of Assembly (Tas.) Journal* 33: 25.

Bacon, C.A., 1991: The coal resources of Tasmania. *Bull. Geol. Surv. Tasm.* 64: 106–108.

Briggs, J.D. & Leigh, J.H., 1995: *RARE OR THREATENED AUSTRALIAN PLANTS.* CSIRO, Canberra.

Buchanan, A.M., 1995: A Census of the Vascular Plants of Tasmania & Index to The Student's Flora of Tasmania. *Tasm. Herb. Occ. Publ. 5.*

Curtis, W.M., 1963: *THE STUDENT'S FLORA OF TASMANIA.* Part 2. Government Printer, Hobart.

Holmgren, P.K., Holmgren, N.H. & Barnett, L.C., 1990: *INDEX HERBARIORUM.* New York Botanical Garden, USA.

McGillivray, D.J., 1973: Michel Gandoger's names of Australian plants. *Contr. N.S.W. Natl Herb.* 4(6): 319–365.

Mueller, F., 1878: *Helichrysum Spiceri. Fragmenta Phytographiae Australiae* 11: 47–48.

Parham, J.W., 1976: ABRS Tasmanian Herbarium Project Final Report. Unpubl. rep.

Rodway, L., 1903: *THE TASMANIAN FLORA.* Government Printer, Hobart.

Simson, A., 1880: On recent additions to the flora of Tasmania. *Pap. Proc. R. Soc. Tasm. 1879*: 43.

Spicer, W.W., 1878: *A HANDBOOK OF THE PLANTS OF TASMANIA.* J.Walch and Sons, Hobart.

Wilson, P.G., 1992: The classification of some Australian species currently included in *Helipterum* and *Helichrysum* (Asteraceae: Gnaphalieae): Part 3 *Anemocarpa* and *Argentipallium*, two new genera from Australia. *Nuytsia* 8 (3): 447–60.

(accepted 11 August 1998)

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 132

Contents

page

Annual report iv

Refereed papers:

VILIZZI, L. & WALKER, K.F. — Age profile of carp (*Cyprinus carpio* L.) in Lake Crescent, Tasmania 1

BRIDLE, K.L. & KIRKPATRICK, J.B. — Why do tall herbs rarely dominate Tasmanian alpine vegetation? Evidence from islands in the Ouse River system 9

MARSDEN-SMEDLEY, J.B. — Changes in southwestern Tasmanian fire regimes since the early 1800s 15

KIRKPATRICK, J.B. & GIBSON, N. — Responses to waterlogging and frost related to the topographic sequences of eucalypt species at three sites in central Tasmania 31

KIERNAN, KEVIN — Holocene landscape instability in the Dazzler Range, northern Tasmania 35

DALTON, P.J. — New locality records for some rare mosses in Tasmania 41

GARDNER, C. — The first record of larvae of the giant crab *Pseudocarcinus gigas* in the plankton 47

CANARIS, A.G. & KINSELLA, J.M. — Helminth parasite communities in four species of shorebirds (Charadriidae) on King Island, Tasmania 49

BICKEL, DANIEL J. — *Cunomyia*, a distinctive new hilarine fly genus from the Tasmanian World Heritage Area (Diptera: Empididae) 59

SHERWOOD, J., WALLS, J.T & RITZ, D.A. — Amathamide alkaloids in the pycnogonid, *Stylopallene longicauda*, epizoic on the chemically defended bryozoan, *Amathia wilsoni* 65

BUCHANAN, A.M. — The presumed extinct *Argentipallium spiceri* (Asteraceae) rediscovered in Tasmania 71

Publication of this volume was generously supported by the Government of Tasmania and the University of Tasmania.

MV 512